LECTURE NOTES ON PHYSIOLOGY

BY

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THE CIRCULATION

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THE CIRCULATION

THE BLOOD

Its Functions in General—The blood performs two important functions—

1. The transportation of, first, substances needed for the nutrition of the body and for the supply of energy to the various tissues, and, second, of substances representing waste products no longer of use to the tissues.

2. The supply of a uniform chemical and thermal environment around all the cells of the body.

Manner of Circulation of the Blood—The blood in performing these functions circulates in a system of closed tubes. It never comes into direct contact with the tissues. All interchanges between the blood and the cells of the body are accomplished through vascular walls of extreme thinness—a single layer of endothelial cells—which form the walls of smallest blood vessels, the capillaries.

Uniform Composition of the Blood—In virtue of its functions of conveying chemical substances for the supply of energy and for the repair of tissue waste the composition of the blood arriving at an organ must differ, and does differ, from that leaving an organ. The degree, however, of variation in the composition of the blood is so slight that it is almost negligible. The preservation of its uniform character is guarded by a most sensitive mechanism in order that the second function served by the blood may be accomplished, namely, that the cells of the body may be surrounded by a uniform environment.

The Red Blood Cells—1. Red blood corpuscles are biconvex circular discs 7.1 to 7.8 microns in diameter by 2.5 microns in thickness at the periphery and 1.0 to 2.0 microns at their centers. Each corpuscle is pale yellow in color, but when crowded together in a suspension such as occurs in fluid blood they impart a red color to the fluid. In mammals the blood cells have no nucleus and

[illegible]

[illegible]

[illegible]

1. [illegible]

2. [illegible]

[illegible]

1. [illegible]

[illegible]

Coagulation of blood

Factors [illegible]

1. primary [illegible]

2. secondary [illegible]

are circular. There are normally 5,000,000 red blood cells to each cu. mm. of fluid blood. (Fig. 1.)

The White Blood Cells—White blood cells are colorless, granular, nucleated cells resembling in every way the unicellular ameba.

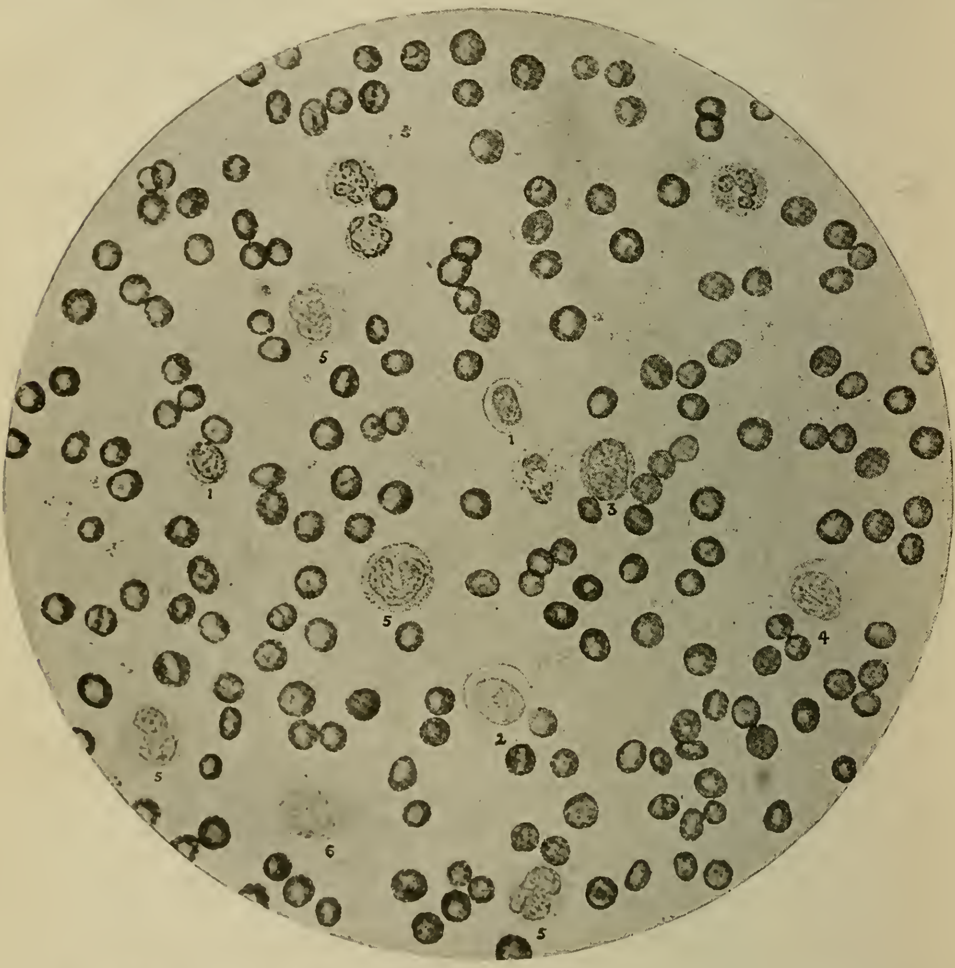


Fig. 1.—Field Showing Red Blood Cells and a Variety of White Cells.

1, Small lymphocyte; 2, Large lymphocyte; 3, Large mononuclear cell, quite different from a transitional cell; 4, Large mononuclear cell, closely resembling a transitional cell; 5, Transitional cell; 6, Degenerated cell. Although 4 definitely and 3 quite probably belong to the transitional cell group, both were included with 2 and classed with the mononuclear cells. Three typical polynuclear cells are shown in the upper part of the field.

They possess the ameba's power of locomotion by throwing out pseudopodia and of ingesting and digesting certain foreign bodies and bacteria.

Most of the colorless cells are a little larger than the red cells.

What [illegible]

[illegible] discharge [illegible]

[illegible]

[illegible]

[illegible]

Pg 131

They are present normally in the blood in the ratio of from 1 to 1000 to 1 to 500 of the number of red cells.

The Blood Plaques—A third corpuscular element in the blood is the blood plaque. These are small circular disc-like bodies of about one-third the size of the red blood cell. The bodies stain a deep blue with the basic anilin dyes and appear to be connected very closely with the process of clotting of the blood. They appear to increase in number in shed blood and to serve as centers for the formation of a network composed of web-like strings called fibrin. In the fluid blood all these elements are suspended in a fluid called plasma.

THE RED BLOOD CELLS

The Red Blood Cells in Greater Detail—*A. The Surface Area of the Red Blood Cells*—The total area of all the red cells in a man of average weight is approximately 3,000 square meters, or 1,500 times the total surface of the body itself. The combined red cells, therefore, offer abundant surface for the absorption of oxygen.

B. Osmotic Relations of the Red Cells—Unless the blood cells are suspended in a solution of salts isotonic with the blood plasma they will not preserve their form. The membrane of the red cell is semipervious to sodium chlorid. If red cells are suspended in a solution of sodium chlorid which is stronger than one which is isotonic with the blood plasma (.9 per cent.), water will pass out of the red cell, causing the latter to shrink. If the solution of sodium chlorid is weaker than this strength, water will pass from the solution into the red cell, causing it to swell, and if sufficiently weak or if the cells are placed in water the red cells will swell up till they burst and thus liberate their hemoglobin or red coloring matter, which passes into solution in the water or weak salt solution. Most neutral salts like sodium chlorid do not pass through the membrane of the red cells.

To urea the cell membrane is pervious. It behaves toward urea as toward water. The cell membrane is also pervious to alcohol, ether and chloroform.

C. The Cell Membrane—The cell membrane is composed of a cholesterin and lecithin compound.

Laking of Blood—Substances Which Rupture the Membrane

[illegible]

[illegible]

Average [illegible]

7 [illegible]

[illegible]

1%

[illegible] 9%.

of the Red Cell and Which Lake Blood—The rupture of the cell membranes of the red blood cells and the obtaining of the hemoglobin or coloring matter of the red cells in solution is termed laking. Though the hemoglobin easily passes into solution, its combination in the red cell is probably solid.

The following substances will lake blood—

1. Ether.
2. Water.
3. Alternately freezing and thawing of blood.
4. Bile salts.
5. Certain foreign serums and other bodies termed hemolysins.

D. The Stroma of the Red Cells—The stroma may be separated by centrifuging and laking the centrifuged deposits and again centrifuging and washing the sediment of corpuscles with acid sodium sulphate.

The stroma protein of the red cells forms only 4 per cent. of the total solids of the red cell. This protein may be broken up by gastric digestion into a protein portion and a body rich in phosphorus. The latter is a nuclein. The nuclein yields the purine bases. The original protein is, therefore, a nucleo protein. The stroma also contains lecithin and cholesterin.

Hemoglobin and Its Compounds—Hemoglobin may be obtained by laking blood as previously described. Its characteristic chemical reaction, which is of physiological importance, is its property of forming an unstable combination with oxygen and to some extent with carbon dioxid.

Oxyhemoglobin—The combination with oxygen is called oxyhemoglobin, and hemoglobin minus the oxygen is called reduced hemoglobin. Simple cooling of solutions of hemoglobin to 10° C. may suffice for crystallization of the hemoglobin. The process may be facilitated by the addition of alcohol to 25 per cent. The best method is to precipitate the globulins by adding a sat. sol. of ammonium sulphate, filtering and then cooling.

Iron forms about .333 to .336 per cent. of the hemoglobin and is very constant in its amount among various animals. From this percentage it is possible to calculate the approximate size of the hemoglobin molecule. Its atomic weight calculated by this method is 16,660.

The oxygen may easily be separated from a solution of hemoglobin by exposing the same in a Torricellian vacuum. The combination with the oxygen is, therefore, a very loose one.

Methemoglobin—The oxygen, however, may be combined with the hemoglobin in a much more stable matter. This combination is called methemoglobin. It is formed in the human body whenever hemoglobin is suddenly liberated. It may be prepared by adding to a solution of oxyhemoglobin an oxidizing or reducing agent such as a ferricyanide or nitrate or permanganate. In any case its formation means two chemical changes. The first of these changes is the liberation of the hemoglobin and the second change is a stable union of the reduced hemoglobin with the oxygen from the oxidizing agent or the free oxygen in the absence of other special oxidizing agents. The following formulas will illustrate two different ways in which oxygen may be combined with hemoglobin:

$$\text{Oxyhemoglobin Hb}\begin{array}{l} \diagup O \\ \quad\ | \\ \diagdown O \end{array}$$

or

$$\text{Methemoglobin Hb}\begin{array}{l} /\!\!/ O \\ \\ \backslash\!\!\backslash O \end{array}$$

It is alleged that methemoglobin contains only one-half as much oxygen as oxyhemoglobin. In the second formula the union would form a more stable combination, such as, for instance, is represented by methemoglobin.

Carbon Monoxid Hemoglobin.—If hemoglobin is placed in an atmosphere of carbon monoxid the radical carbon monoxid unites with the hemoglobin, forming carbon monoxid hemoglobin. This is a compound of far greater stability than oxyhemoglobin, so that when exposed to oxygen the latter will not replace the carbon monoxid. The color, however, of carbon monoxid hemoglobin is a bright red, like oxyhemoglobin; hence it is that people poisoned with carbon monoxid may appear of a good color and yet be suffering from deficient oxygenation of the blood. Moreover, supplying them with oxygen in liberal quantities does not result in the formation of oxyhemoglobin and consequently does not relieve the anoxemia.

These four compounds, oxyhemoglobin, reduced hemoglobin, methemoglobin and carbon monoxid hemoglobin, are definite chemical substances of great physiological importance and each have their own characteristic spectra. (Fig. 2.)

Oxyhemoglobin gives two absorption bands between the lines C and D. Reduced hemoglobin gives one broad absorption band

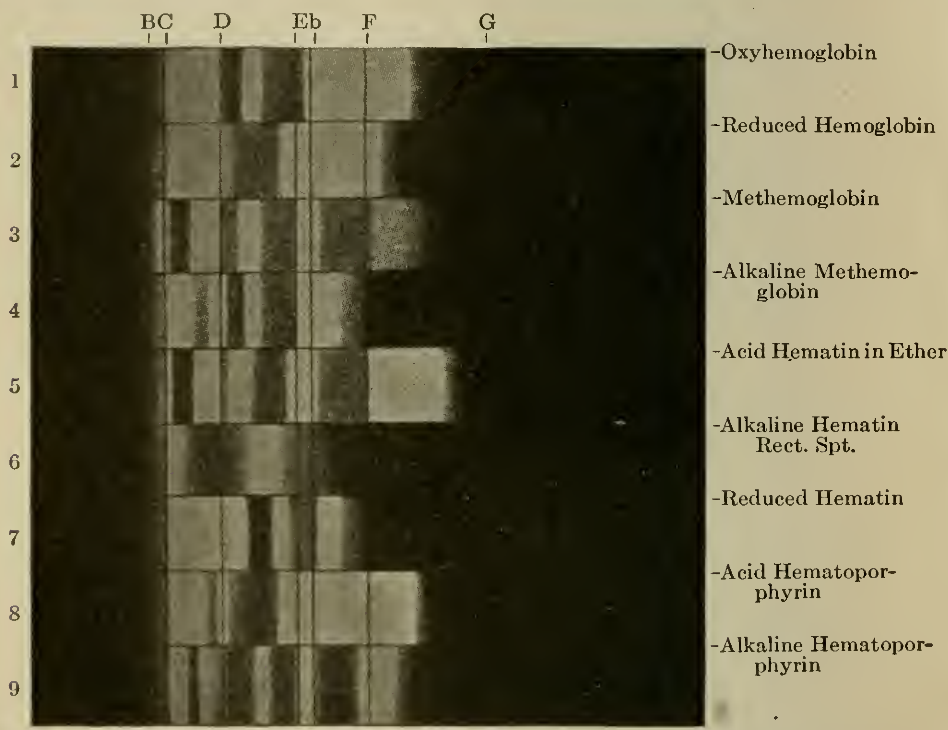


Fig. 2.—Spectrum of Hemoglobin and Its Derivatives (Mac Munn).

between the two lines C and D, and carbon monoxid hemoglobin gives again two lines very similar to oxyhemoglobin, but the center of each band is nearer to the red end of the spectrum.

The Chemical Nature of Hemoglobin—Information upon the chemical nature of hemoglobin can only be derived by a study of its derivatives.

Treated with weak acids or alkali or heated to 70° C., hemoglobin may easily be split into a protein portion and an iron containing colored portion, the prosthetic group. The protein portion is classified with the histones. About 94 per cent. of hemoglobin is this protein, and the chromogenic group forms about 4.5 per cent. and is called hematin.

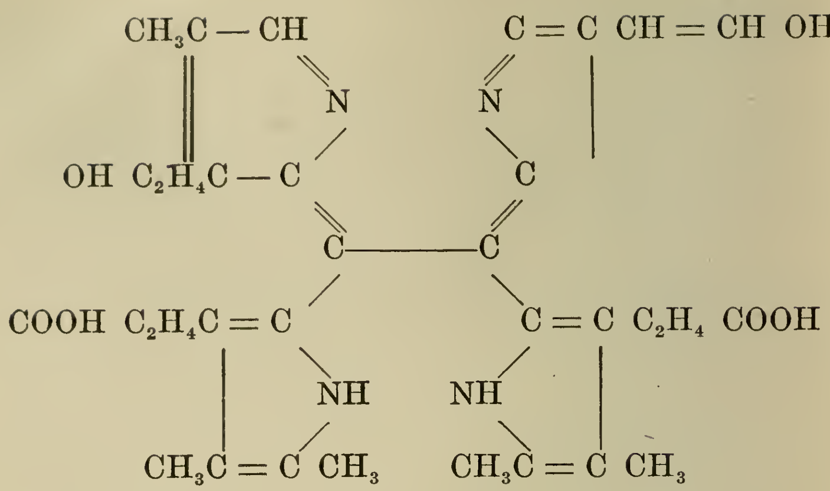
A. Hematin.—Hematin may be more readily obtained from the hydrochlorid of hematin, which is known as hemin. The latter can be obtained by heating blood, even a very small quantity, as a dried blood stain, with acetic acid and sodium chlorid. It separates as well-defined reddish brown needle-like crystals, which are so characteristic that obtaining them has been used as a test for blood stains.

Hematin forms compounds with acids and alkalis which are known as acid and alkali hematin. Both of these give characteristic absorption bands in the spectrum.

B. Hemochromogen.—Ordinary alkali hematin may be reduced by reducing agents such as ammonium sulphid to form another body known as reduced alkali hematin. The last may be separated directly from blood by the preparation of hematin by means of an alkali in the presence of reducing agents. This reduced alkali hematin is called hemochromogen. It also gives a characteristic spectrum, even in dilutions of 1-25,000th parts of water, and is of much importance, as it represents the portion of hemoglobin capable of forming loose combinations with oxygen. This view is further confirmed by the possibility of obtaining carbon monoxid hemochromogen by treating carbon monoxid hemoglobin with alkalis in the presence of a reducing agent.

C. Hematoporphyrin—Hemin contains one atom of chlorin and one atom of iron. Hematin contains one atom of iron. When hematin is treated with concentrated sulphuric acid the atom of iron is split off and the resulting body is called hematoporphyrin. This body possesses a formula which is isometric with bilirubin, the chief pigment contained in bile, and also gives a characteristic spectrum.

D. Hemopyrrol—From hematoporphyrin can be obtained three substances known as hemopyrrols, the mixture of which gives reactions which are also given by urobilin. These same substances may be also obtained from the chlorophyll of plants. The formula of each of these three substances is known, and, according to Willstätter, hematoporphyrin is formed of four pyrrol groups united together. A knowledge, therefore, of the derivative of hemoglobin makes possible an understanding of its chemical structure. Willstätter gives the following structure formula for hematoporphyrin:



The relationship between hemoglobin or its derivatives and the chief pigment of the bile and urine is significant as regards the origin of these latter substances from the blood pigment. The relationship between hemoglobin, the oxygen-carrier of the animal body, and chlorophyll, the deoxidizer of the carbon for plant life, is also of interest.

The Probable Chemical Structure of Hematin—To obtain hemin from hematoporphyrin the insertion of one atom of iron and chlorin is all that is necessary.

Hematin is to be regarded as identical with oxyhemochromogen and is a far more stable body than reduced alkali hematin or hemochromogen, in so far at least as the iron concerned. In the case of oxyhemochromogen or ordinary hematin only the strongest acids can split off the iron, which is not the case with reduced alkali hematin.

Reduced hematin seems to be a simple combination of iron and hematoporphyrin and can be easily prepared synthetically from these two components. It is possible to affect a combination of globin and hemochromogen and also a combination of other proteins with hemochromogen. Other proteins may then replace the globin in combination with the chromogenetic group of the red cells.

Source of the Red Cells—In the embryo the first red blood cells are formed by the differentiation of the mesenchymic cells from which the first blood vessels are formed. A similar growth of red cells of the fetus occurs in liver and spleen and later in the bone marrow. During the earlier periods the majority of red cells

are nucleated. As full term is reached the nucleated cells become less and less frequent, until at birth practically all of the cells are of the non-nucleated type.

Provision must exist in the adult for the continued formation of red cells, if merely to replace those which are lost or destroyed by hemorrhage, other accident or disease. A sensitive mechanism in the healthy adult or growing child keeps the number of red blood cells constant. In health pigment which is derived from the red cells is constantly leaving the body in the urine and feces. This steady loss must be repaired. The site of repair is the bone marrow.

The structure of bone marrow eminently fits it for this function. It forms a rigid tissue protected from pressure and composed of large spaces through which a slow circulation may occur. In this tissue one may find all stages from the marrow cells to the fully formed red blood cell. The marrow of the bones is the only tissue which is seen to undergo alteration when blood cell formation is stimulated by hemorrhage. Within it all stages between certain nucleated marrow cells and the non-nucleated red cells are found. Many nucleated red cells are found within the marrow, and after hemorrhage these gain access to the general circulation.

The portions of the marrow which are red are those chiefly engaged in the formation of the red cells. Under normal conditions the red marrow occupies only the epiphyses of bones, but when a demand for increased formation of red cells exists the red portion of the marrow extends longer or shorter distances into the shaft.

The length of life of the red blood cell is unknown; sooner or later each red cell must perish. As it becomes older disintegration sets in and the corpuscle becomes a prey to the process of phagocytosis. In the hemolymph glands and in the spleen, fragments of red cells may be recognized within the bodies of phagocytic cells.

The liver obtains its supply of pigment for the manufacture of bile from the disintegrated red cells. The liver also contains much iron. Both an increased secretion of bile and storage of iron within the liver may be caused by injecting hemoglobin or by those conditions leading to rapid destruction of the red blood cells. In some cases actual hemoglobin crystals have been observed within the liver. We must, therefore, regard the liver as the chief place of destruction of the red blood cells.

THE WHITE BLOOD CELLS

Varieties of the White Cells—These are colorless, granular or hyaline cells capable of ameboid movement, varying in size, but the majority are larger than the red blood cells. Normally there are 5,000 to 8,000 in every cu. mm. of blood. They are classified into the following varieties. (Fig. 3.)

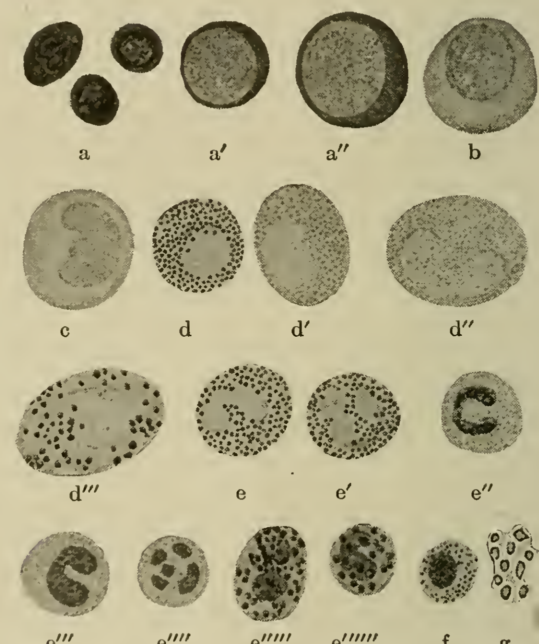


FIG. 3.—a, Lymphocytes; a′, a″, large lymphocytes; b, large mononuclear lymphocyte; c, transitional leukocyte; d, eosinophil myelocyte (bright red granules); d′, d″, neutrophil myelocyte (brown granules); d‴, basophil myelocyte (blue granules); e, e′, polynuclear eosinophil; e″, e‴, e″″, polynuclear neutrophil leukocyte; e′′′′′, e′′′′′′, polynuclear basophil leukocyte; f, small neutrophil pseudolymphocyte; g, blood-platelets.

Polymorphonuclear Cells.—Multinucleated or lobed nucleated cells. Relatively to the size of the nucleus there is considerable protoplasm in which are numbers of neutrophile granules, that is, they do not stain a bright red with eosin or a blue with methylene blue, but rather a brown color, indicating a position between the granules, reacting to basic and acid dyes. These cells form 70 per cent. of the white blood cells in the normal individual.

Cells with an Hourglass or Horseshoe-shaped Nucleus and Only

a Few Neutrophile Granules—These may be regarded as transitional cells between the hyaline white cell and the polymorphonuclear white blood cell. They form about 1 per cent.

Lymphocytes—Small cells with a deeply staining nucleus, around which is only a small amount of hyaline protoplasm. They form 23 per cent. of the white blood cells.

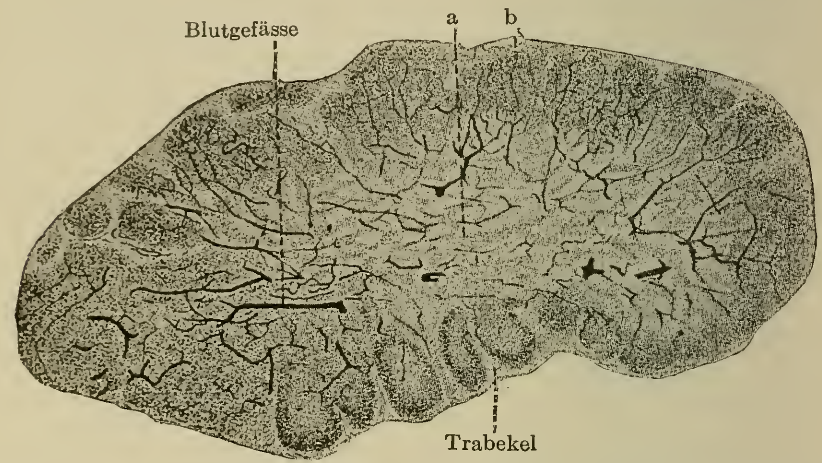


FIG. 4.—SECTION THROUGH A MESENTERIC LYMPH GLAND OF A CAT OF WHICH THE BLOOD VESSELS HAVE BEEN INJECTED. MAGNIFIED 50 DIAMETERS. It shows well the central sinuses (a) and the cortical follicles (b).

Large Mononuclear or Hyaline Corpuscles, Very Large Cells, Two and Three Times the Diameter of a Red Cell—They possess a large feebly staining nucleus, around which is a relatively large amount of hyaline very faintly staining protoplasm; 2 per cent. are normally present.

Eosinophile Cells—A large cell with a lobed crescentic or reniform nucleus and a surrounding protoplasm in which are imbedded many large size granules, taking a deep or eosin stain, and hence appearing a bright red. They are normally present to the extent of .5–2 per cent.

Mast Cells—These cells have a lobed nucleus, but large basophilic granules, taking a deep stain with methylene blue. They form about one-half of one per cent. of the total number of white blood cells.

The Site of Origin of the White Cells—Origin of the white blood cells is not the same for all varieties of white cells. The lymphocytes come from the lymph glands. Each gland consists of

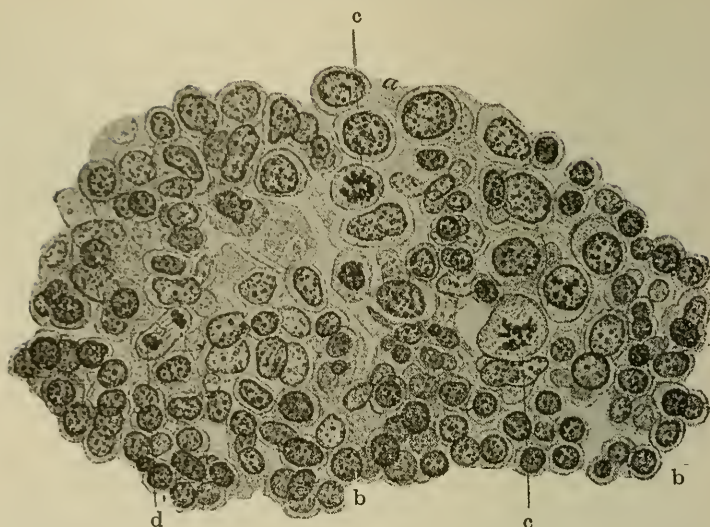


FIG. 5.—A SECTION THROUGH A GENERATIVE CENTER OF A CORTICAL NODULE OF A LYMPH GLAND, SHOWING CELLS IN MITOTIC DIVISION.

a, Large mononuclear leukocytes; b, small lymphocytes which are especially numerous near the lower borders of section; c, monaster of the metaphase of a dividing cell; d, diaster or anaphase of a dividing cell. (Kolliker.)

FIG. 6.—SECTION OF A MESENTERIC LYMPH NODULE OF AN ADULT, SHOWING A PART OF THE PERIPHERY OF THE NODULE. 325 DIAMETERS.

k, capsule; kc, generative center with many nuclear figures, a number of cells showing degenerating forms (f); l, lymphocytes arranged in rows; s, lymph sinus. (Kolliker.)

a central portion, consisting largely of lymphatic vessels between trabeculæ and filled with lymph, and in which are suspended lymphoid cells. The periphery of the gland is composed of nodules of lymphatic tissue. (Figs. 4, 5.) In the center of these nodules the lymphocytes are produced; these centers are known as the germ

FIG 7.—FROM A SECTION THROUGH HUMAN RED BONE-MARROW. X680.

a, f, Normoblasts; b, reticulum; c, mitosis in giant cell; d, giant cell; e, h, myelocytes; g, mitosis; i, space containing fat cells. (Bohm, Davidoff, Huber.)

areas, and in them the cells are larger, stain less intensely and show frequent mitotic figures. The periphery of the nodule consists of a series of anastomotic channels communicating with one another and with the channels in the center of the whole lymphatic gland, which leads to the hilum or the end of the gland, from which the efferent veins leave the gland and convey the new cells produced by the gland to the blood stream. The arterial supply of the gland also enters at the hilum. (Fig. 6.)

The polymorphonuclear leucocyte and eosinophile cells are derived, like the red blood cells, from the bone marrow. It is doubtful whether the hyaline white blood cell is derived by a trans-

formation of the lymphocytes or whether it comes also from the bone marrow by a variation in the transformation of the myelocytes. (Fig. 7.)

Function of the White Blood Cells— *Phagocytosis* is the power possessed by the white blood cells of ingesting and digesting and transporting foreign bodies or bacteria which have gained entrance to the circulation or the tissues of the human body. They remove degenerated tissue. In various larvæ they remove useless parts and excessive muscle no longer of use in the future development of the insect. The polymorphonuclear white cells are the chief phagocytes. Probably the lymphocytic and large hyaline corpuscles possess some phagocytic powers. It is more uncertain in how far the eosin and basophile cells are phagocytic.

They do not seem to engulf bacteria or foreign bodies, but it is possible that by discharging their granules they may destroy bacteria or prepare them for ingestion by the more completely phagocytic cells. The leucocytes are not the only phagocytic cells in the body.

BLOOD PLATELETS

The third corpuscular elements found in the blood are the blood platelets. They may be obtained for demonstration purposes by pricking the finger through a drop of osmic acid. When the mixture of blood and osmic acid is then examined, in addition to the red and white cells a third corpuscular element is found about one-third to one-half the size of a red cell. They may be isolated or grouped; each corpuscle is a biconvex body with usually numerous processes. Within them is a darker staining, more refractive body considered to be a nucleus. Their number within the blood has been estimated to be between 180–800,000 per cubic mm. (Fig. 8.)

Relation of the Blood Plaques to Clotting—It is very easy to show that the blood platelets in the mammalian blood are intimately connected with the process of clotting. They immediately collect around an injured spot in the wall of a vein, fusing together and, when the blood is examined in normal salt solution, filaments of fibrin are seen to radiate from them. (Fig. 9.)

Their Existence within the Circulating Blood—They are ab-

sent in frogs' and birds' blood and from defibrinated mammals' blood, and their existence in the freely circulating blood has been

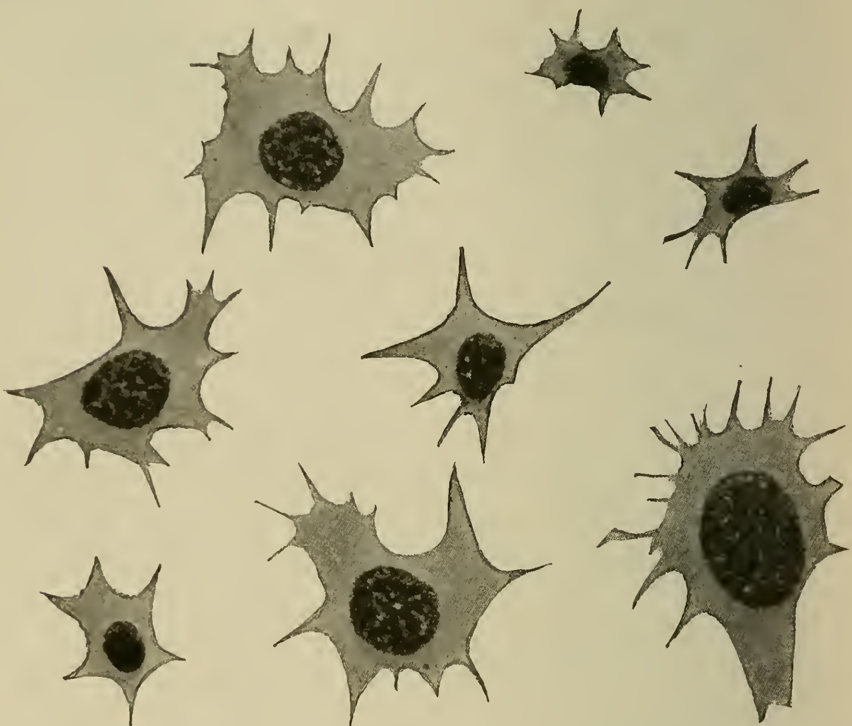


FIG. 8.—BLOOD PLATELETS FROM HUMAN BLOOD, STUDIED IN DEETJEN'S SOLUTION AFTER FIXATION WITH 1% OSMIC ACID AND STAINED WITH HEMATOXYLIN. 3,200 DIAMETERS. (Rauber-Kopsch.)

questioned, because it is possible to obtain uncoagulated blood, for instance, within a platinum loop kept at body temperature, in which

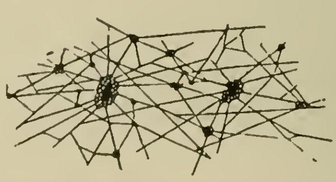


FIG. 9.—NETWORK OF FIBRIN, SHOWN AFTER WASHING AWAY THE CORPUSCLES FROM A PREPARATION OF BLOOD THAT HAS BEEN ALLOWED TO CLOT.

Many of the filaments radiate from small clumps of blood-platelets. (Schäfer.)

they are also absent. In the uncoagulated blood obtained in this manner no blood platelets exist on microscopical examination, and

yet when such specimens cool the platelets make their appearance.

The platelets may be separated by first centrifuging off the red and white cells from the plasma which has been rendered non-coagulable by the addition of sodium oxalate or peptone. If plasma is cooled to 0° C. a precipitate indistinguishable from the platelets forms. Probably, therefore, the platelets do not exist as such within the circulating blood. Those fluids which display them best probably do so because they form them and not because they preserve them. The platelets are virtually a precipitate. After formation they rapidly undergo disintegration.

COAGULATION OF BLOOD

Conditions Preventing Coagulation—1. Within an excised ligatured vein the blood will remain fluid sometimes for days.

2. Birds' blood does not clot unless it comes into contact with the tissues. It may be obtained with care in a glass beaker without having come into contact with the tissues, and will remain fluid.

3. If blood is received into vessels coated with oil or paraffin and, if scrupulous care has been exercised to exclude dust, clotting may be prevented for hours.

4. Blood cooled to 0–1° C. and kept at this temperature will remain fluid indefinitely.

5. Sodium oxalate or sodium citrate added in strength of 1–1.5 per cent. will prevent clotting.

6. 0.3 gram of peptone per kilo of body weight injected into an animal will prevent clotting. The blood must be drawn off immediately, as the peptone causes a rapid death of the animal.

7. The addition of leech extract or hirudin will prevent clotting. It may be injected into the blood stream or mixed immediately with blood as it is drawn.

8. Cooled horses' plasma which has been allowed to stand will not clot upon raising the temperature if the plasma is filtered through two layers of filter paper.

After warming the addition to the filtrate of the washing of a blood clot or tissue extracts or a little fresh serum will cause clotting in such cooled plasma.

First Conclusion on the Mechanism of Clotting—Lime Salts

Essential—Oxalate plasma will clot on the addition of calcium chlorid. The addition of the lime salt causes a precipitate of calcium oxalate; the blood will not coagulate until the calcium chlorid has precipitated all the oxalate and exists in a slight excess in the blood.

The first conclusion on the process of clotting is, therefore, that lime salts are necessary for the process. It is further necessary that the lime salts should exist in the form of a salt, in an ionized condition, as, for instance, calcium chlorid or calcium sulphate. Its mere presence in solution as in the form of a double soluble salt, which, for instance, is formed between the normal lime salts of the blood and sodium citrate, when the latter is used to prevent clotting, is not sufficient to permit clotting.

This explains why sodium citrate, which does not precipitate the calcium of the blood, will still prevent clotting.

Second Conclusion—Fibrinogen Necessary—The second conclusion on the process of clotting is that a globulin, fibrinogen, which is present in plasma but not in serum, is necessary for the process. Fibrinogen may be separated from oxalate plasma by half saturation with common salt. It separates as a granular precipitate at first and then as a stringy, slimy mass, which may be taken out by stirring on a glass rod, washed with the salt solution and redissolved in distilled water. It may be precipitated by warming to between 56–60° C. from either its pure solution or from the original plasma. No precipitate may be obtained from the serum left over until it is heated to 68° or 70° C. If a few drops of calcium salts are added to the solution of the separated and only partially washed fibrinogen, redissolved in water, it rapidly clots.

Third Conclusion—Another Body, Thrombin, Necessary—Something else besides the calcium and fibrinogen is necessary for clotting. A solution of thoroughly washed fibrinogen will not clot upon merely the addition of lime salts; but can be made to clot upon the addition of either a little serum or the washings from a blood clot or the watery extract of an alcohol coagulated serum. The substance which is added in the serum or washings is called thrombin. It has been called fibrin ferment, but the fact that accurate experiments show that it is used up in the process of clotting, even though it acts in extremely small quantities, and the fact that its action on fibrinogen is almost independent of

temperature have been accepted by some observers as evidence though hardly sufficient evidence that it is not a ferment.

Fourth Conclusion—Thrombin Is Formed from a Prothrombin—The part played by calcium in the process of clotting is in connection with the formation of thrombin. This is true because thrombin and fibrinogen will form a clot when mixed together in the entire absence of calcium salts, but the substance which with the calcium forms thrombin and which we may call prothrombin may be separated from oxalate plasma by allowing it to stand at 0° for two or three days and then filtering through several layers of filter paper. It is possible to prepare pure thrombin by extracting fibrin with 8 per cent. solutions of sodium chlorid and getting rid of the proteins by shaking with chloroform. The filtrate left by filtering the cold oxalate plasma will not coagulate upon the addition of lime salts, but if we treat the precipitate with a little calcium chlorid and add it to the filtrate a clot will form. More than this, a clot will be obtained if the precipitate, provided it is not thoroughly washed, plus a little calcium is added to a pure solution of fibrinogen.

Fifth Conclusion—Thrombokinase and Thrombogen Are Necessary—Two substances beside the calcium salts are necessary for the formation of thrombin; only one of these may properly be designated as prothrombin. It will be a little better to designate it now as thrombogen. It has been said that a precipitate formed in the cold will produce a clot with fibrinogen in the presence of calcium. This is only true if the precipitate is not thoroughly washed, though, even if thoroughly washed, it will produce a clot in the plasma filtrate. Two substances, therefore, are necessary, not merely the precipitate but another substance contained in the plasma, of which sufficient adheres to the precipitate produced by cold to form with it, in the presence of calcium, thrombin. Extracts made from tissues can be shown to contain the same substance which exists in the washed precipitate formed from oxalate plasma by cold. These extracts in the same manner as the precipitate will form a clot when mixed with oxalate plasma, together with lime salts, but will not form a clot in solutions of fibrinogen unless a little plasma is also added to the solution of fibrinogen.

The substance contained in the tissue extracts and in the precipitate produced by cold from oxalate plasma is called thrombokinase.

It may be obtained not only from extracting tissues but also from stroma of red cells and from leucocytes or lymph cells. In fact the granular precipitate containing it is the blood platelets. The other substance is thrombogen and is contained only in the plasma of the blood.

The existence of this other substance, thrombogen, is denied by Howell, who considers that the prothrombin is always present in the blood, and that it immediately reacts with lime salts to form thrombin whenever the action of antithrombin is prevented by neutralization with a thromboplastic substance. In other words, the thromboplastic substance of Howell replaces the thrombokinase of other authors, and instead of participating with another body to form thrombin this other body corresponding to thrombogen is prothrombin while the thromboplastic substance corresponding to thrombokinase is active by binding or neutralizing the antithrombin. In any case, in addition to fibrinogen, prothrombin and lime salts another body formed when blood is shed is needed. The new body, according to Howell, binds the antithrombin, which in the circulating blood prevents the formation of thrombin from prothrombin in the presence of lime salts.

It has been mentioned that blood platelets are absent from birds' blood and consequently the thrombokinase. It is for this reason that birds' blood will only coagulate when allowed to come into contact with the tissues.

The Source of the Thrombokinase—The crucial step, then, in the process of clotting is the liberation of the thrombokinase in the form of the blood platelets, but we have seen that very strong reasons exist that these elements do not exist as such within the blood. Can they come by the rapid disintegration of leucocytes? It does not seem probable, inasmuch as these can be seen alive for two or three days in oxalate plasma. We must, therefore, either believe in the preexistence of the blood platelets and assume that they are elements of a most perishable character, so that the slightest contact with any other substance than the normal endothelium of vessel wall will cause them to disintegrate or, and this is more probably the correct view, that the blood platelets are formed at the time of injury to the wall of the blood vessels and the contact of the plasma with a foreign substance; that they are merely a precipitate of thrombokinase, first presenting evidence of organiza-

tion after precipitation, but rapidly undergoing disintegration.

Explanation of the Failure for Clotting to Occur within the Vessels—*Inhibition of Clotting within the Vessels*—Closely related to the crucial factor in clotting, the liberation of the thrombokinase, is the question of why is this substance not liberated within the vessels.

Only one answer is possible, namely, the nature of the surface forming the walls of the vessels. The walls of the vessel act in some manner which prevents the precipitation of thrombokinase or thromboplastin, possibly by a secretory activity of the endothelial cells themselves or in virtue of the physical characters of the lining endothelium itself.

The following facts indicate that the nature of the surfaces of the walls of the vessels, aside from any secretory activity on the part of the endothelial cells constituting them, is an important factor in the failure of thrombokinase to be liberated from the plasma within the vessels.

The fact that blood will remain for so long fluid if received into dust-free paraffin or oil tubes.

That birds' blood may be made to coagulate even if drawn without contact with the tissues, if after drawing it is subjected to much trauma by violently whipping it or filtering it through a clay cell. Evidence, however, exists that a mechanical insult is not the only factor in the prevention of clotting within the vessels. Under certain conditions blood serum can be shown to have a strong inhibitory effect on thrombin.

We know that leucocytes and red cells are being continually destroyed within the body. What, then, becomes of the thrombokinase in them. The circulating blood, therefore, must possess some means of neutralizing thrombokinase or thrombin. This conclusion is further confirmed by the fact that the injection of thrombin or thrombokinase within limitations into the blood stream will cause no clotting. We must, therefore, assume the presence of antithrombin or antikinase and, on account of the rapidity with which it must be formed, that it is produced by the endothelial cells of the vessels themselves. Intravascular clotting can be produced if very strong solutions of thrombin are injected into the vessels.

The Nature of Thrombokinase—Normal saline extracts of tis-

sues rich in cells, such as the thymus or lymph glands will cause intravascular clotting, even the alkaline solution of the acid gastric digest of these tissues will cause intravascular clotting. These tissues contain nucleo proteins and are rich in phosphorus and contain much lecithin. The precipitated acid gastric digest contains as much as 25 per cent. of lecithin. The view that intravascular prevention of clotting is due in part to the formation of antithrombin is further strengthened by the fact that injections of small amounts of thrombin or the injection of large amounts in small doses actually diminishes the coagulating power of the plasma. Repeated injections may actually annul the coagulability of the blood. This result is exactly what one would expect from the known principles of immunity, assuming that the prevention of intravascular clotting depends upon the production of antithrombin.

Metathrombin—Not all the thrombin is used up during clotting. Much still remains in the serum; and can be demonstrated by the usual test with a solution of fibrinogen. Thrombin, however, rapidly disappears so that in two or three days no traces of it may be found in the serum. We know that it has been transformed, because such serum can be reactivated by the addition of acid or alkali. The transformed product has been called metathrombin. It has been suggested that the metathrombin may merely be a combination product of thrombin and that the action of acid or alkali simply serves to break up this combination.

Thrombin itself is very stable, resisting the temperature of boiling water for limited periods. Its solutions may be evaporated to dryness and heated to 135° C. without destruction of the thrombin.

Explanation of How Clotting Is Prevented by the Various Means Mentioned According to the Above Theory of Clotting—*Cooled plasma* simply precipitates the thrombokinase. Sodium sulphate inhibits coagulation merely by the presence of an excess of salt. It will coagulate on dilution.

Magnesium sulphate plasma will coagulate on dilution, but not if it has been centrifuged after standing for 24 hours. It slowly precipitates thrombokinase.

Sodium Florid Plasma—Sodium florid precipitates the calcium

salts, but also carried down, entangled with the lime salts, thrombogen.

Herudin plasma acts like an antithrombin. It preserves quantitive relations.

Peptone plasma stimulates within the vascular system in antibody to coagulation.

Transudates do not clot, but can be made to clot upon the addition of thrombin or the washings of a blood clot. Transudates do not contain thrombokinase or thrombogen.

ESTIMATION OF THE BLOOD AND ITS CONTENT

Methods of Estimating the Total Quantity of Blood—A small sample of blood must be subjected to hemolysis by dilution with 100 volumes of water. This serves as a sample. The animal is then bled and minced in known quantities of distilled water and the minced products washed with the same. By a comparison of the two standards the total amount of hemoglobin is estimated. The dog contains 7.7 per cent. of weight in blood. The average amount of blood in man is 4.9 per cent. of the body weight, and in fat people may be only 1/30 of the body weight.

The figure 1/13 obtained from bleeding criminals is probably far too high. Haldane has devised a method for estimating the total quantity of blood by estimating calorimetrically from a sample of blood the amount of carbon monoxid which this sample contains in an individual who has inhaled a known quantity of carbon monoxid gas. The saturation of hemoglobin with oxygen is first determined. The experimenter then knows the percentage amount of hemoglobin which has been saturated with carbon monoxid, and from the known amount of gas absorbed the absolute amount of carbon monoxid hemoglobin formed. If he then knows the percentage of hemoglobin originally present in the individual's blood he is in a position to calculate the total quantity of blood.

Causes Varying the Total Quantity of Bloods—The total amount of the blood varies with the blood pressure. Any lowering of the blood pressure causes fluid from the tissues to pass in the blood. It may even be diluted to 50 per cent. by this process. It varies with the oxygen tension of the air breathed and, therefore, is less in high altitudes.

Estimation of the Total Number of Corpuscles—Estimation of

the number of corpuscles and amount of plasma. The corpuscles may be counted in specially ruled chambers adapted for use under the microscope and made for the purpose. The volume of the corpuscles is 50 per cent. of that of the blood.

Estimation of the Plasma by Centrifuging the Blood—The amount of plasma may be determined by subtracting the protein of the blood corpuscles from the amount of protein of the whole blood.

Estimation of the Oxygen—The oxygen content of the blood may be estimated by disassociating the oxygen of laked blood by potassium ferrocyanid and reading off the amount in cubic cc. of gas.

Estimation of the Specific Gravity of the Blood—The specific gravity of the blood may be measured by dropping a drop of blood into different dilutions of glycerin and water until a dilution is found in which the drop will neither float nor sink. It varies in man from 1057 to 1066. In woman from 1054 to 1061. The specific gravity of the serum is 1028 to 1032 and of the corpuscles 1090.

The Reaction of the Blood—The blood is alkaline and may be measured by titration against a decimal solution of sodium hydrate. It amounts to .2 gram of sodium hydrate per 100 cc. of blood. In laked blood the alkalinity is twice as much.

The degree of alkalinity depends on the indicator used. The only accurate method is to estimate the number of free ions by an electrical method. It is found to contain very few more OH ions than water. Litmus gives a fairly accurate estimation of the relation between the reaction of the blood and its carbon dioxid carrying power. This power is in proportion to the alkalinity to litmus.

Osmotic Pressure of the Blood and Corpuscles—The osmotic pressure of the blood is a most important physical character of the blood. Upon it depends in a large measure the variation in exchanges between the blood and the tissues. The pressure may be estimated by determining its freezing point. In the human being normally this is 0.56. The corpuscles and laked blood possess the same freezing point.

Constancy of the Salt Content—The conductivity of the blood is determined solely by the ions which it contains and, therefore, by the proportion of disassociated salts contained in it.

The amount of salts is very constant and so the conductivity of the serum is constant, but the conductivity of the blood varies with its content of corpuscles, as these are not permeable to the ions, and, therefore, presents resistance to the free circulation of the ions.

COMPOSITION OF BLOOD

Total solids, 20 to 25 per cent.

A. Fibrin, 0.2 to 0.4 per cent. { Fibrinogen. { Thrombogen.
Thrombin. } Thrombokinase.

B. Serum. { Serum albumen. Serum globulins, divided into two fractions, the euglobulins and the pseudoglobulins. } United to form a unit substance, serum protein, which is not ionized, nor will it pass through a porous cell, as serum globulin alone will do.

The proteins of the serum form 7–8 parts, the salts 1 part.

Sodium chlorid, 60 per cent. (2.701 per 1,000 grams of blood).

Sodium carbonate, 30 per cent. (0.746 per 1,000 grams of blood).

Potassium, sodium in other combinations, calcium chlorid, and phosphates—traces.

Fats, cholesterin, lecithin, dextrose, urea—traces.

C. Corpuscles—Total solids, 30 to 40 per cent.

a. Hemoglobin, 90 per cent.

b. Lecithin cholesterin salts, 10 per cent. Sodium and potassium phosphate compose a large portion of the salts (0.325 and 1.202 per 1,000 grams).

ANALYSIS OF 1,000 GRAMS OF BLOOD OF A MAN 25 YEARS OF AGE

Corpuscles, 513.02 grams.

Water	349.69 grams
Hematin (including iron)	7.70 "
Proteins	151.89 "
Inorganic salts (excluding iron)	3.74 "

	Grams.			Grams.
Chlorin	0.898		Chlorid of potassium	1.887
Sulphuric acid	0.031		Sulphate of potassium	0.068
Phosphoric acid	0.695		Phosphate of potassium	1.202
Potassium	1.586		Phosphate of sodium	0.325
Sodium	0.241	=	Soda	0.175
Phosphate of calcium	0.048		Phosphate of calcium	0.048
Phosphate of magnesium	0.031		Phosphate of magnesium	0.031
Oxygen	0.206			
	3.736			3.736

Plasma, 486.98 grams.

Water	439.02 grams
Fibrin	3.93 "
Albumen, etc.	39.89 "
Inorganic salts	4.14 "

	Grams.			Grams.
Chlorin	1.722		Sulphate of potassium	0.137
Sulphuric acid	0.063		Chlorid of potassium	0.175
Phosphoric acid	0.071		Chlorid of sodium	2.701
Potassium	0.153		Phosphate of sodium	0.132
Sodium	1.661	=	Sodium carbonate	0.746
Phosphate of calcium	0.145		Phosphate of calcium	0.145
Phosphate of magnesium	0.106		Phosphate of magnesium	0.106
Oxygen	0.221			
	4.142			4.142

THE CIRCULATION

The Mechanism by Which the Blood Reaches the Tissues—In order that the blood may perform its functions a system of closed tubes permeating the whole body has been developed. The important features of this system embrace not only the tubes themselves but a central pump, the heart, and a definite length of very minute vessels, the capillaries, possessing thin walls, permitting diffusion through their walls and ramifying every portion of every tissue. Thirdly, there is a delicate mechanism for controlling the pressure of the blood and the amount in different portions of the vascular system.

The Various Classes of Substances Which the Blood Transports—The chemical substances with which it is necessary to supply the tissues may be divided into two kinds, (1) oxygen or the active agent of combustion, and (2) building material or combustible substances.

These two varieties of substances must be obtained from entirely different sources and organs. The oxygen is taken into the body in a free state as such. The building material must undergo complicated changes in the organs of digestion.

Provision must also be made for the elimination of waste prod-

ucts and the modification of the substances in the blood or the addition of specific chemical substances which stimulate or control functions in the body.

The Three Kinds of Vessels—For the performance of these functions a special set of minute vessels having very thin walls and called capillaries is needed. In the human body, with the exception of the set of capillaries devoted to the taking in of oxygen, these sets of capillaries are all branches of a main vessel or artery coming off from the central pump. From the various sets of capillaries with one exception the blood is returned to the heart by a common system of branched tubes, the veins, before reentering the circulation. They thus constitute in part separate complete circuits, though with the exception of the brain, kidney and heart anastomoses with neighboring branches is frequent.

The one exception to this manner in which the blood is returned to the heart is the portal circulation, in which two sets of capillaries are in series with the arteries supplying the system and interposed between it and the veins, returning the blood to the heart.

The Peculiarity of the Oxygen Receiving Portion of the Circulation in Man, Fish, and Amphibian—The set of capillaries devoted to the intake of oxygen in man is a part of an entirely separate system originating in the heart and ending in the heart. Thus all the blood in the body must traverse the pulmonary circulation before it can reach the rest of the body.

The union between these two systems, the oxygen system and the reconstructive system, is through the heart, which, therefore, in man is really a double communicating pump. In fishes the heart is only a single pump, there being but one auricle and one ventricle. All the blood passes through the gills, where the oxygen is taken up before it reaches the rest of the body.

From these gills it passes directly to the systemic circulation. We may speak of the gills in fishes as connected up in series in the same manner as the portal circulation in man.

The fish's heart represents the primitive type of heart. Amphibia (frogs) represent a stage of development between the fish's heart and man's heart. There are two auricles and one ventricle.

The oxygen circulation leaves the heart by a common vessel with the systemic circulation, but returns by a separate vessel to the ventricle through a separate auricle.

STRUCTURE OF THE BLOOD VESSELS

The structure of the large arteries, of the arterioles and of the veins differs and this difference corresponds to a difference in function.

The Structure of the Arteries—All arteries possess relatively thick walls composed of muscular, elastic and fibrous tissue. In the largest arteries there is a greater amount of elastic tissue in proportion to the amount of muscular tissue than in the small arteries.

The function of the large arteries is chiefly one of conduction, to receive the blood from the heart and to pass it on. Their walls are elastic and resisting. They are never called upon to diminish to any degree in caliber. For this reason yellow elastic tissue is a far more important component in them than muscular tissue.

The Structure of the Smaller Arteries—The smaller arteries, on the other hand, are often required to undergo marked contraction; one of the most important means which the body possesses of controlling blood pressure is by this contraction. Their coats, therefore, are well supplied with muscle. Their internal coat is called the intima. It consists of a layer of endothelial cells resting upon a basement membrane of yellow elastic tissue. External to this coat is a middle layer, the media. It is thick and composed entirely of unstriped muscular fibers arranged in both a circular and longitudinal layer. The third and most external coat is called the adventitia. It is composed chiefly of white fibrous tissue with a few elastic fibers. From the very smallest arterioles the elastic tissue disappears altogether. The wall consists entirely of endothelium and muscle tissue.

It is the practically sole function of the veins to conduct the blood. Because of the usual intravascular pressures within them it is only necessary, therefore, that their walls should be capable of a small increase of blood pressure. Corresponding with this demand upon them, their walls are composed almost entirely of white fibrous tissue, and they fulfill a subsidiary reservoir-like function of storing a greater or smaller proportion of the circulating blood.

An increase of only 1 or 2 mm. of Hg. will cause an increase in the capacity of the veins of 50 per cent., and 60 mm. of Hg. will completely distend them. (Fig. 10.)

On the other hand, it will require 80 mm. of Hg. to cause a 50 per cent. distention of the arteries and a pressure of 130 to 160 mm. to completely distend them.

The total sectional area of the branches of the arteries and veins is greater than that of their parent vessels. This increase in section area is most marked in the transition from the arterioles and venules to the capillaries. The total sectional area of the capillaries is 800 times that of the aorta.

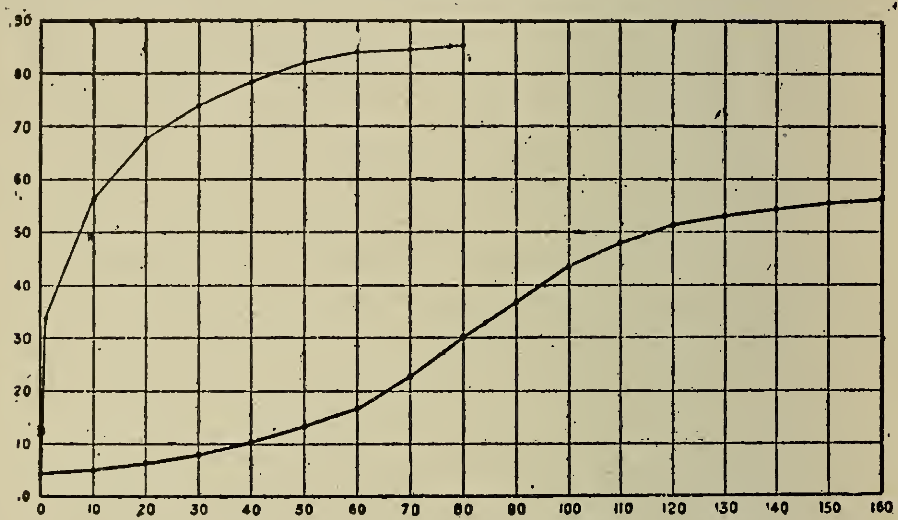


Fig. 10.—Curves of Distensibility of an Artery (Thick Line) and of a Vein (Thin Line).

The figures at the left side of the diagram represent the capacity of a section of the vessel when distended under a certain pressure, expressed by the figures on the base line in mm. Hg. (Starling.)

The impulse of the heart beat is forcible enough to cause the blood to spirt from a divided artery in jets at intervals corresponding to the heart beat.

The jet-like character of the spirt is less marked in hemorrhage from the smallest arteries, partly because of their size and distance from the heart and partly because of the resistance offered to the impulse from the heart by the elasticity of the walls of the vessels. The impulse from the heart beat does not transmit itself through the capillaries. From a divided vein the blood does not spurt, but merely flows out in a continuous stream.

By tying into an artery a cannula which is in series, by means of a solution of sodium citrate, salt and carbonate isotonic with the blood, with a mercury manometer we may record the blood

pressure and pulse changes. The record is made upon a revolving disc called a kymograph by means of an aluminium scratcher floating up and down upon the surface of the mercury in the manometer.

THE BLOOD PRESSURE

The normal blood pressure in the arteries is about 120 mm.; in the capillaries it is 20 to 40 mm. Hg. and in the veins not more than 1 to 2 mm. of Hg. In the large veins near the heart the blood pressure may be negative. The inertia of the instruments causes much deformity in the record of blood pressure curves taken in

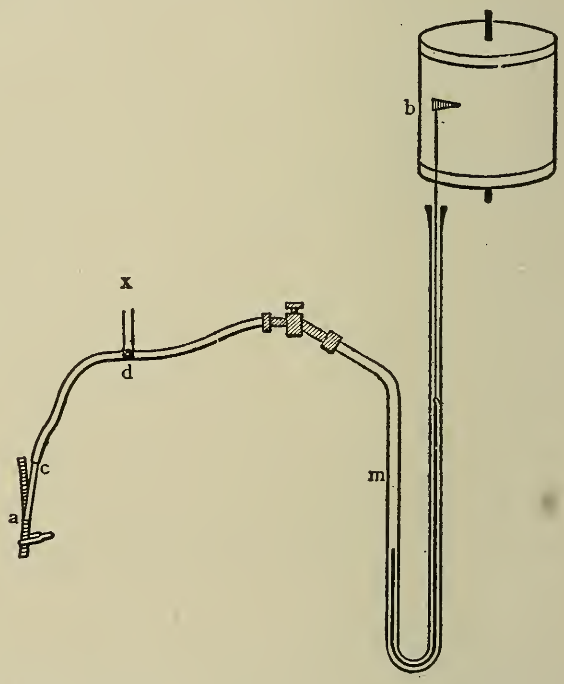


FIG. 11.—ARRANGEMENT OF AN APPARATUS FOR TAKING BLOOD PRESSURE TRACING.

a, Artery (carotid); c, cannula; d, threeway cock; m, mercurial manometer; b, drum covered with smoked paper; x, tube to pressure bottle. (Starling.)

this manner. This deformity may in a large measure be prevented by a tracing made from a delicate tambour protected by a thick rubber reducing bulb, as in Erlanger's, Hurthle's or Frank's sphygmograph.

The General Character of the Curves and the Pressures Which They Represent—Using any of these instruments, it will be observed

that the curve representing the blood pressure rises and falls with each beat of the heart. The lowest portion of the curve records the diastolic pressure and the highest point the systolic pressure. The average between the two is the mean pressure. The range between the two is known as the pulse pressure. In man the systolic pressure is 120 mm. of mercury, the pulse pressure is about 45 mm., and the diastolic pressure is about 75 to 85 mm.

Method of Measuring the Arterial Blood Pressure in Man—The arterial pressure may be measured in man by compressing the brachial artery by means of a distensible rubber cuff, fitting around the upper arm and protected by a leather cover. The

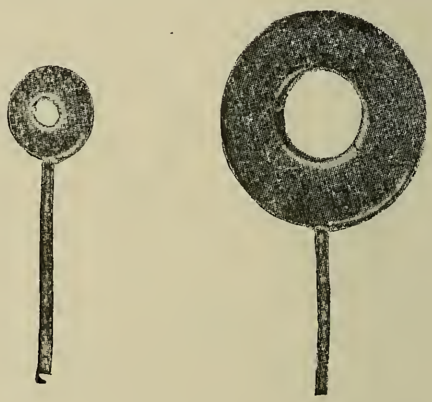


Fig. 12.—Circular Rubber Bags, Capable of Inflation, for Taking Venous or Capillary Blood Pressure.

interior of the rubber cuff is connected with a manometer and the cuff is distended until the brachial artery is obliterated. This point is determined by feeling for the disappearance of the radial pulse. (Fig. 11.)

Method of Measuring the Venous Pressure—The venous pressure may be estimated by compressing a vein beneath a circular rubber bag, which is also connected with a manometer, and gradually distending the same.

The obliteration of the vein is observed through a glass covering the hole in the center of the bag, which at the same time offers resistance to the bag as it is distended. (Figs. 12 and 13.)

The Location of Greatest Fall in Pressure in the Circulation—The fall of blood pressure between the veins and arteries is due to the fact that the arterioles possess relatively small openings and empty their contents into the veins, the walls of which are easily

distensible, so that they offer practically no resistance to the flow of blood through them. To a certain extent it is as though the capillaries emptied into a large flaccid, reservoir-like bag.

The location of the various places of greatest fall in pressure within the circulatory system is determined by the sites of greatest resistance to the current of blood.

A Mechanical Arrangement Reproducing the Pressure Relations of the Various Portions of the Circulation—The whole question is best understood by comparing the circulation to a reservoir of infinite size which communicates at its bottom with a horizontal tube of uniform bore and from which at regular intervals a series

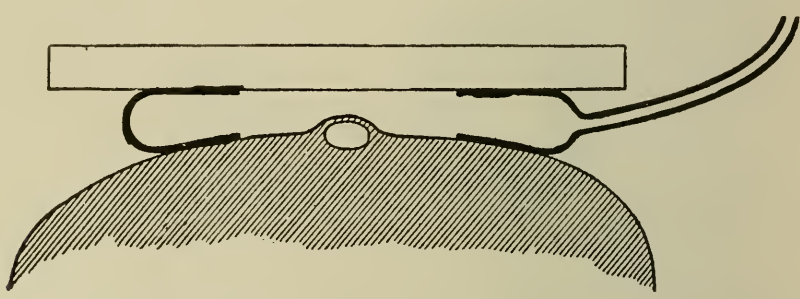


Fig. 13.—Same Rubber Bag as in Fig. 12, Shown in Cross Section, as Applied Over a Vein and Covered with Glass, Through Which the Degree of Pressure Necessary to Obliterate the Vein May Be Determined.

of perpendicular pipes arise. (Fig. 14.) As the water flows out of the reservoir through the distal opening of the horizonal pipe it will occupy at any one time different levels in the upright tubes. The height of these levels will all be in the same straight diagonal line. It will be possible, in other words, to draw a straight diagonal line across the top levels of the water in the upright tubes.

This line, however, will not cut the reservoir at its top, but at a distance below the surface of the water within it. This distance will represent the head under which the water flows out of the pipes.

If we introduce at any point between the upright pipes a stopcock, by which the resistance to the flow of water through the horizontal tube may be increased, one straight diagonal line will not connect the level of the water in the upright pipes on both sides of the stopcock. Two lines are now required. On each side of the stopcock a separate straight line will connect the levels of

1. Describe 4 kinds of nervous system

2. " embryological development

3 describe the diff nervous end organs.

4. Describe neurone

5 Classify nerves

6 What is velocity how measured

7. What is actual function direction along nerve fibres

8 What excites a conduction passage of nerve impulses

9 Site of fatigue

10 Define 4 types of reflexes

the top of the fluid and the line on the proximal side will be higher than the line on the distal side. The level of the water in the upright pipes, which are proximal to the point of increased resistance, will be higher than in those pipes distal to it. (Fig. 15.)

The effect of the increased resistance at the stopcock represents the effect of the increased resistance offered by the arterioles and the capillaries to the circulation of any fluid through a closed

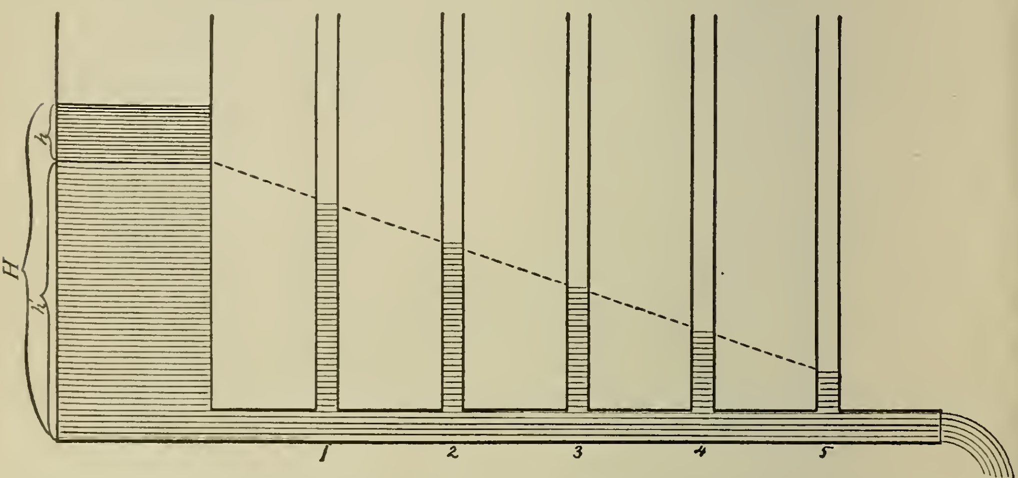


Fig. 14.—Schema to Illustrate the Side Pressure Due to Resistance, and the Velocity Pressure. (Tiegerstedt.)

H, A reservoir containing water; 1, 2, 3, 4, 5, the outflow tube with gages set at right angles to measure the side pressure; h′, the portion of the total pressure used in overcoming the resistance to the flow; h, the portion of the total pressure used in moving the column of liquid—the velocity pressure. (Howell.)

system of tubes, and may be used to demonstrate that the velocity of the circulation is proportional to the pressure and inversely as the resistance.

$$V = \frac{L\ P}{R}$$

In this illustration the reservoir furnishing the constant pressure under which the fluid flows through the pipes represents the heart. The stopcock represents the resistance offered by the arterioles and the difference in pressure on its two sides the difference between the arterial and venous pressure. If the stopcock is opened widely the water will quickly run out of the reservoir and the pressure on the two sides of the stopcock become equal. The circulation within the body differs from this crude mechanism in

of direct current under normal
condition.

12. What are the factors causi

that it forms a close circuit beginning and ending in a central pump, the heart. Nevertheless, the resistance offered by the veins to the collection of blood within them and the power of the heart to pass out from itself all the blood brought to it by the veins creates conditions resembling those in the mechanism in so far that when the arterioles dilate the blood tends to flow out from the arterial side of the circulation into the venous side. The power of the arterioles, of maintaining a certain favorable degree of constriction,

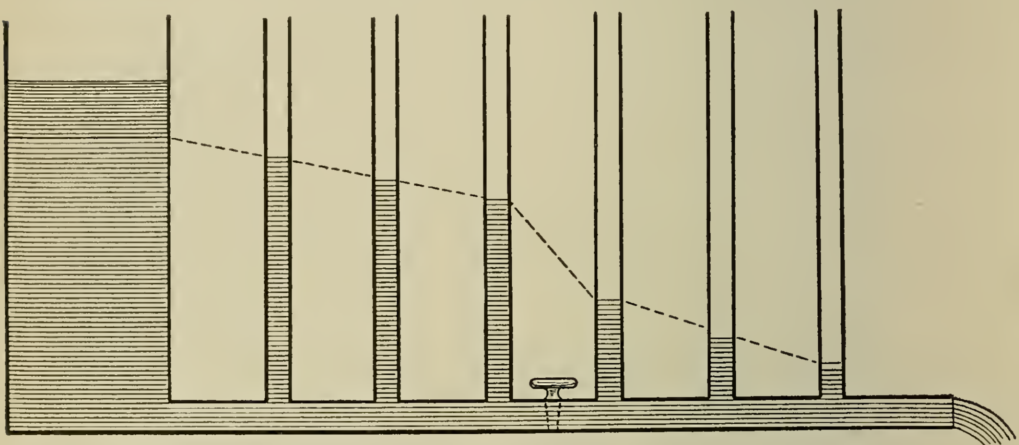


Fig. 15.— Schema Like the Preceding, Except That a Stopcock Is Inserted at the Middle of the Outflow to Imitate the Peripheral Resistance of the Capillary Area.

The relations of internal pressure on the arterial and venous sides of this special resistance is shown by the height of the water in the gages. (Howell.)

permits of the blood, as it is returned to the heart by the veins, being piled up on the arterial side of the circulation at a pressure relatively high to that in the veins. It will be appreciated at once that in such a closed circuit operating for the maintenance of this favorable distribution of the blood two other factors are of equal importance to the degree of constriction in the arterioles. One of these is a steady supply of blood to the heart by the veins and the other is a favorable strength of heart beat. If a certain portion of the vascular system unduly dilates, an abnormal quantity of blood will be stored up in this dilated portion and prevent the return of a favorable quantity to the heart. Inasmuch as the central pump or the heart cannot give out more than it receives, if it receives an insufficient quantity, it will give out too little blood to keep the pressure high on the proximal side of the arterioles, i.e., on

the arterial side of the circulation. If, on the other hand, the central pump beats too freely or stops, blood will run out through the arterioles, however much constricted, and soon the pressures on both the proximal and distal sides of the arterioles will become equal.

The Site of the Greatest Fall in Pressure in the Circulation—The distribution of the different blood pressures in circulation throughout the various vessels of the vascular system demonstrates that the greatest change in resistance to the current of blood is situated in the arterioles. (Fig. 16.)

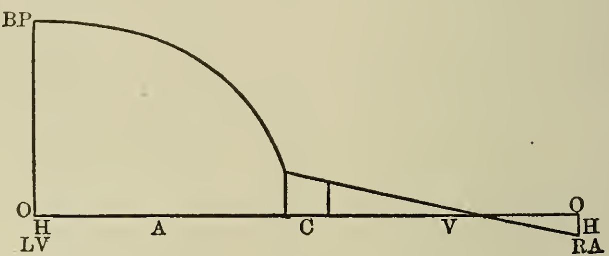


Fig. 16.—Scheme of Blood Pressure.

A, In the arteries; C, in capillaries; and V, in veins; OO, line of no pressure; LV, left ventricle; RA, right auricle; BP, height of blood pressure. (Starling.)

The total sectional area of the arterioles, while greater than that of the arteries, is much less than that of the capillaries, whereas the difference in the diameter of the arterioles and capillaries amounts to very little.

The fact that the greatest resistance to the flow of blood is offered by the arterioles may be shown by an experiment which increases their diameter, as, for instance, a division of the upper part of the spinal cord. The increase in the diameter of the arterioles thus produced will reduce the blood pressure one-half.

The Relative Pressures in the Various Arteries, Veins and Capillaries—The following are the blood pressures in the various parts of the circulation:

Large arteries (carotid), 90 mm. Hg. (65–110).
Medium-sized arteries (radial), 85 mm. Hg.
Capillaries, 15 to 40 mm. Hg.
Small veins of the arm, 9 mm. Hg.
Portal vein, 10 mm. Hg.

Inferior vena cava, 3 mm. Hg.
Large veins of neck and chest, 0 to —8 mm. Hg.

The Relation of the Rapidity of the Circulation to the Needs of the Tissues—Inasmuch as one important function of the blood is to supply the tissues with oxygen and nutritive substances and to remove from them waste products, any diminution of the quantity of the blood passing through the capillaries, below a degree which is sufficient for the need of the tissues, will impair the activities of the cells of the body. A diminution of a favorable quantity of blood within capillaries will be brought about by any diminution in the rapidity with which the whole blood of the body passes through them.

The Actual Velocity of the Circulation through the Aorta, Capillaries and Large Veins—Under normal condition the velocity of blood in the aorta is about one-half a meter a second. In the capillaries it is approximately one-half a millimeter a second. The average length of a capillary is about 0.5 mm. The total sectional area of the large veins near the heart is about twice that of the aorta; the velocity of the blood through them is therefore one-half of that through the aorta. The blood remains, therefore, within the capillaries approximately one second. In this brief time the tissue must receive from the blood sufficient oxygen and deliver to it their waste quantities of carbon dioxid and other substances. The oxygen and waste products cannot, moreover, pass directly from and to the blood, but must do so through the capillary wall of endothelium and the lymph filling the lymph spaces immediately external to the capillaries and intervening everywhere between them and the tissues. Everything, therefore, related to the well-being of the tissues depends upon the velocity of the circulation through the capillaries. A clear conception, therefore, of the factors controlling the rapidity of the capillary circulation is of much importance.

An Increase in the Force of the Heart Beat—The effect of increasing the force of the heart beat upon the rapidity of the capillary circulation can readily be appreciated without further explanation.

Changes in the Caliber of the Arterioles—The effect, however, of changes in the caliber of the arterioles is far more complicated and must be considered as operating under two conditions:

1. First the effect of changes in the caliber of limited portions of the circulatory system, as, for instance, portions supplying a single organ of such a small size that dilatation or contraction of its arterial supply can have no effect upon the general blood pressure. In this instance we have to deal with only the local effects of the changes in the caliber of the vessels; a contraction of the afferent vessels diminishes the amount of blood entering the capillaries of the area or organ in question, while a dilatation produces the opposite effect. In the former case the tissues are less well sup-

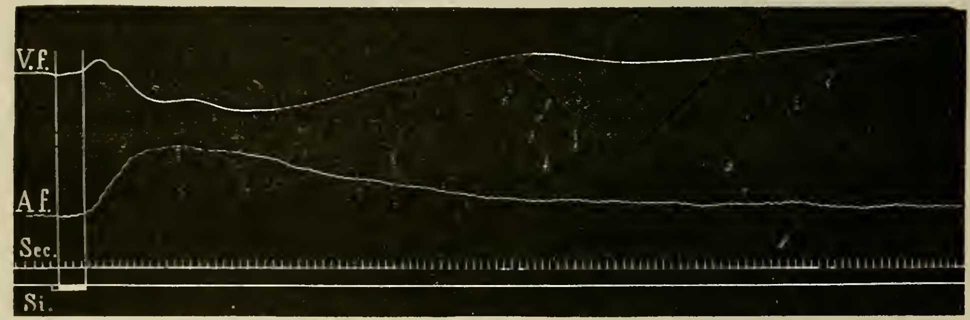


Fig. 17 Illustrates the Reversed Effects upon Arterial and Venous Pressures in the Facial Artery and Vein Produced by Stimulation of the Vasoconstrictors.

At first there is a slight rise of venous pressure due to the inflow of blood into the veins at higher pressure; then a marked fall of venous pressure, and finally the venous pressure becomes greater than at first.

V.f. = venous pressure
A.f. = arterial pressure
Sec. = time in seconds.
St. = signal marking period of stimulation.

plied with blood and their function is suppressed. In the latter case the tissues are well supplied and their function is stimulated. The blood on emerging through the efferent venules may be still of a bright red color and even impart a pulsation to the veins.

2. Generalized changes in the caliber of the arterioles throughout the whole body or, at least, over a sufficient area to seriously affect the general blood pressure, may produce quite different effects. In order to understand the consequences of generalized changes in the caliber of the arterioles the effects of deviations from that degree of contraction which is most favorable to the needs of the tissues must be considered.

Excessive Arterial Constriction—First, what will be the consequences of a greater degree of contraction than the optimal

amount—that amount, in other words, which permits of the swiftest current of blood through the capillaries? Such a contraction will immediately cut down the amount of blood which is permitted to pass into the capillaries, and the blood retained upon the arterial side of the system will be retained at a higher blood pressure. (Fig. 17.) The increased pressure will evoke from the heart a stronger beat up to a certain degree of constriction; the increase of pressure and stronger beat of the heart will compensate for the constriction of the arterioles by forcing more blood through them than can pass through the same size vessels, under normal arterial pressures.

Beyond a certain point, however, the burden of a continued contraction of the arterioles becomes too great for the compensating power of the heart and cuts down the amount of blood entering the capillaries to such a degree that the swiftness of the capillary circulation is materially slowed.

During the unfavorable degrees of arterial constriction, though the blood pressure on the arterial side of the circulation is greatly increased, yet an excess of blood cannot be said to be stored up upon the arterial side of the system. The diminution of space on the arterial side of the system, due to the contraction of the arterioles, more than balances the effect of the increase of blood pressure upon the capacity of the arterial system. As the augmentation of the heart beat fails to compensate sufficiently in forcing the normal quota of blood through the capillaries, a time is reached when the excess of blood retained upon the proximal side of the arterioles begins to be dammed back through the heart upon the venous side of the circulation, and this condition still further diminishes the rapidity of the capillary flow.

Excessive Arterial Dilatation—What will now be the effect upon the capillary circulation of a dilatation of the arterioles?

When the arterioles dilate beyond that degree which is most favorable to the speed of the capillary circulation a large quantity of blood at first flows out from the arterioles through the capillaries and into the venules, and the capacity of the arterial side of the circulation becomes somewhat increased as a result of the arterial dilatation.

For these two reasons the arterial blood pressure becomes reduced and still further reduced because the low blood pressure

evokes a weaker beat from the heart, although the latter is, to a certain degree, compensated for by an increase in the frequency of the heart beat. In this connection it must not be forgotten that the combined sectional area of the capillaries is much greater than that of the arterioles, while the diameter of the smallest arterioles differs little from that of the capillaries. Consequently when the arterioles dilate it is as though the passage between the arterial and venous sides of the circulation was opened wide, with no resistance to oppose the rapid flow of blood away from the arterial side of the circulation and its collection within the wider bed of the capillaries and venules.

Effect of Long Continued Excessive Capillary Dilatation—The caliber of the capillaries and venules is largely dependent upon the intravascular pressures to which they are subjected, and while their walls possess a certain power of elastic contraction, the latter is only sufficient to enable them to cope with the normal conditions of the circulation and not sufficient to enable them to resist the sudden onrush of blood from the arterial side of the circulation, and particularly is this true of the capillaries and veins of the splanchnic area.

A considerable quantity of blood collects, therefore, upon the venous side of the circulation. This quantity of blood may very properly be termed the portion of the blood which holds the balance of power of the circulation, because its extraction from the arterial side of the circulation brings about such a reduction of the arterial blood pressure, by virtue of the failure of the return to the heart of an optimal quantity of blood, that after the first onrush of blood into the capillaries and venules there is a reduction of that force which drives the blood on through the capillaries and veins. A number of other conditions acting solely from the venous side of the circulation share with this reduced arterial pressure in being responsible, as long as the arterial dilatation continues, for the failure of the power of the capillaries and venules to empty the excess of blood which they contain back again from the venous side of the circulation through the heart into the arterial side. In extreme conditions after prolonged periods of reduced arterial pressure these additional factors, acting from the venous side of the circulation, may be efficient alone in preventing a return to

the normal conditions of the circulation even after the causes of the primary arterial dilatation have passed away.

Influence of the Special Characters of the Portal Circulation—An important factor influencing the speed of the capillary circulation, or at least maintaining a diminution of the speed of the capillary circulation after changes in the caliber of the arterioles has once occurred, is the character of splanchnic circulation. The splanchnic circulation includes the blood supply to all the abdominal organs which supply tributaries to the portal vein. This vein receives the blood from the abdominal organs, from the stomach, the intestines, pancreas, and the spleen, and instead of returning its blood directly to the inferior vena cava it breaks up into a second set of capillaries within the liver. There are, therefore, two sets of capillaries intervening between the afferent arterioles to the splanchnic area and those efferent venules which return the blood of this area to the interior vena cava. A diminished arterial blood pressure is, therefore, less able to force any excess of blood entrapped, as it were, between these two sets of capillaries than in any other portions of the vascular system.

The vascular system of the splanchnic area forms a considerable portion of the total circulation of the body, such a large proportion that an excess of blood entrapped within it is capable alone of materially reducing the general arterial blood pressure. If, therefore, a dilatation of the arterioles to this area causes an excess of blood to flow into its capillaries and venules the immediately ensuing reduction of the arterial blood pressure will be sufficient to render the general arterial blood pressure powerless to empty the distended venules and capillaries of the splanchnic area through the second set of venules of the portal circulation within the liver; and yet there will be sufficient pressure transmitted through the dilated afferent arterioles of the splanchnic area to successfully oppose any power of the tributary capillaries and venules of the portal system to empty themselves by their own contractile power. In other words, the rate at which the blood will be delivered through the capillaries of the portal vein within the liver to the inferior vena cava will be less than the normal rate, and yet the wide open arterioles of the splanchnic area will constantly keep an excess of blood within the tributary capillaries and venules of the portal vein.

The Inertia in the Elastic Contraction of the Capillaries—This condition of affairs makes clear the part played by the second factor acting from the venous side of the circulation and responsible in part for the diminution of the speed of the capillary circulation under conditions of generalized arterial dilatation.

The second factor may be termed the inertia of the contractile power of the capillaries and veins. The pressure within the veins and capillaries after an initial distention becomes progressively less the longer the time during which they are subjected to an increase of intravascular pressure. Even after short periods of distention their power of contraction in response to a diminution of the pressure under which the blood is pumped into them, inasmuch as the general arterial pressure cannot fall until they first become distended, is far slower than the readjustment of the normal arterial caliber and never adequate until the amount of blood entering these capillaries and venules becomes cut down by a contraction of the arterioles.

The reality of this inertia becomes evident after prolonged periods of distention, when even a contraction of the arterioles becomes no longer able to bring about a normal distribution of the blood within the body. One factor explaining this inertia in the contractile power of the capillaries and venules may be a certain loss of elasticity in the walls of these vessels. Unquestionably the most important factor is the loss of the compressing force normally exerted upon the capillaries and veins from without. After more or less prolonged periods of increased intracapillary and venous pressure there occurs a diminution of the thickness of the extra capillary and venous lymph space. The lymph becomes actually forced out of these spaces and the flow through the thoracic duct increased. Under these conditions a return of the capillaries and venules to their normal caliber is resisted by the failure of any force returning the lymph to the extravascular spaces and consequently by the tendency to develop a negative pressure in these spaces. The sequestration in this manner of a portion of the total quantity of blood of the body within the veins necessarily means that less blood will be received by the heart. If less blood is received by the heart, the heart in turn cannot deliver the normal quantity to the arterial side of the circulation, so that this consequence forms another seg-

ment of the train of events contributing together in a vicious circle, as it were, to keep the blood pressure low.

The Influence of the Shortened Total Diastolic Period—Still another factor must be added to these consequences. Under the conditions of lowered blood pressure the heart attempts to overcome the reduced pressure by an increased frequency of its beat. The rate of the heart is increased at the expense of diastole. Such a condition means that the total period during which the heart is receiving blood is cut down so that for this reason, even though it may only be a corollary to the fact that less blood flows to the heart, the heart is unable to deliver a normal output to the aorta.

The Influence of Hydrostatic Pressure in the Venous System—The above discussion has not considered the possible effects of hydrostatic pressure. The mechanical factors involved in the circulation of the blood have been considered upon the basis of a horizontal system of tubes. The influence of hydrostatic pressure cannot be entirely neglected. Its effects, however, become chiefly manifest, especially in the splanchnic area, under conditions of dilatation of the arterioles. Indeed, as will later be explained, it is upon the presence of valves in the veins, the extravascular pressure (muscular contractions around the veins) and chiefly the power of response of the arterioles to increase of intravascular pressure that at all makes possible a normal return of blood to the heart under conditions of vascular dilatation, including as it must an inhibition of the myogenic contractions of the arterial wall, the force of hydrostatic pressure must be added to all other factors mentioned in preventing a normal return of blood to the heart. In such an animal as a rabbit, for instance, with its very lax abdominal wall, it is said that death may result alone from suspending the animal by its ears. The cause of syncope in the human being is an inhibition of the vasomotor center, and the beneficial effects of the prone position in this condition make evident the powerful effect of hydrostatic pressure in preventing the return of the blood to the heart in conditions of vascular dilatation of the arterioles. Inasmuch as the portal vein and its tributaries have no valves and the contractions of the abdominal muscles are probably not transmitted so directly to the portal vein and its tributaries, the influence of hydrostatic pressure must be considered to be an important factor when it is added to the other factor operating through this

portion of the circulation in preventing the discharge of an excess of blood contained within it.

THE HEART CIRCULATION

THE ANATOMY OF THE HEART AND THE COURSE OF BLOOD THROUGH THE HEART

The heart is a muscular organ containing four chambers. (Fig. 18.) Two of these chambers, the right and left ventricles, are concerned in pumping the blood into arteries, which convey the blood respectively to the lungs and to the body. The other two chambers of the heart, the right and left auricles, receive the blood respectively from the body and the lungs. The right auricle receives the blood back from the systemic circulation through the superior and inferior vena cava. The blood entering the heart through these vessels is venous blood, containing much carbon dioxid. It passes from the right auricle into the right ventricle. By the contraction of this ventricle it is forced into the pulmonary artery, which conveys the blood to the pulmonary capillaries. From these vessels it passes into the pulmonary venules and then by the four pulmonary veins to the left auricle of the heart.

The left auricle by its contraction forces the blood into the left ventricle, and from this ventricle it is forced into the aorta. The branches of the aorta carry the blood to the capillaries of every portion of the body, from which it is returned by the venules and veins and finally by the superior and inferior vena cava to the heart, whence it begins once more the circuit of the body.

The passage of the blood in only one direction through each chamber of the heart depends upon the presence of valves between the auricles and ventricles and at the entrance to the aorta and pulmonary artery.

The valves placed between the auricles and ventricles are flat or flap-like structures, composed of fibro-elastic tissue lined with endothelium. One edge is attached to the margin of the auriculo-ventricular opening. By the opposite free margin they are attached with tendinous cords to the summits of little muscular elevations projecting into the cavity of the heart from the opposite ventricular walls.

These projections are called papillary muscles and by their contraction aid in maintaining a closed position of the valve during a ventricular contraction. (Fig. 19.)

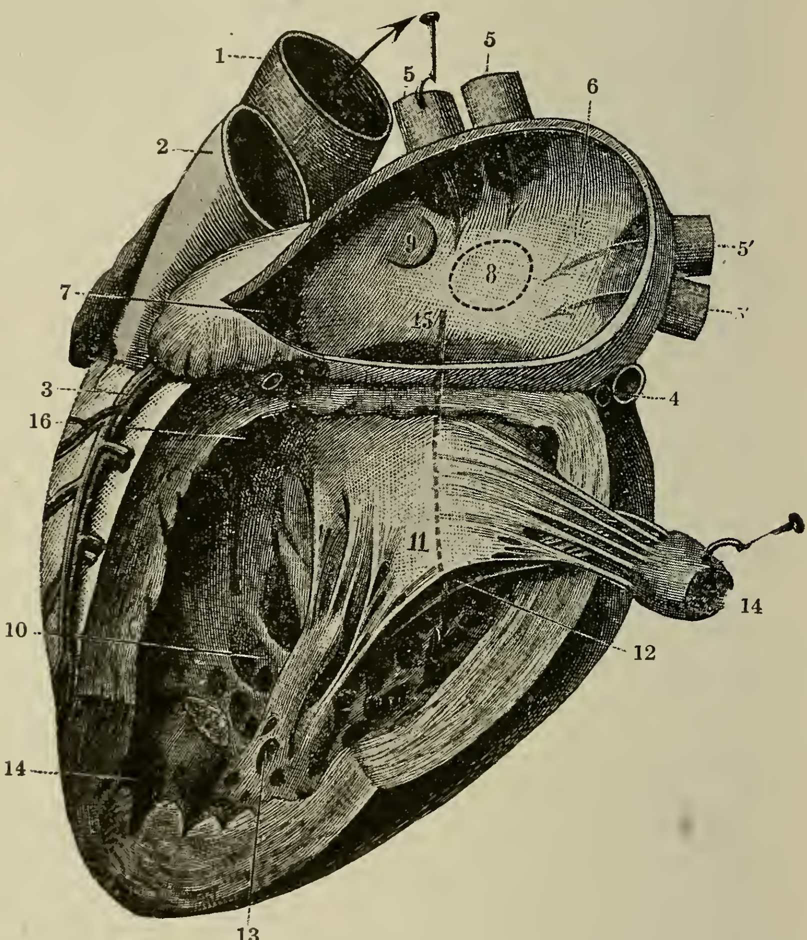


Fig. 18.—The Heart with Left Ventricle and Auricle Opened.

1, aorta; 2, pulmonary artery; 3, anterior coronary vessels; 4, posterior coronary vessels; 5, 5′, right and left pulmonary veins; 6, cavity of left auricle with, 7, the left auricular appendix; 8, zone corresponding to the foramen ovale; 9, semilunar fold or termination of eustachian valve; 10, cavity of left ventricle; 11, 12, internal and external flaps of the mitral valve; 13, posterior papillary muscle; 14, divided anterior papillary muscle; 15, line indicating the left auriculoventricular opening; 16, the aortic orifice communicating with the ventricular portion, so called the aortic chamber.

Between the right auricle and right ventricle there are three flaps belonging to the auriculo-ventricular valve. Hence, it is called the tricuspid valve. Two flaps, on the other hand, guard the left auriculo-ventricular opening. It is called the mitral valve.

The openings to the pulmonary artery and aorta are guarded by three cup-shaped valves or pockets attached at their external periphery to one-third of the margin of the aortic or pulmonary opening. The free margin of each pocket possesses at its center a small fibro-cartilaginous nodule, the corpus Arantii.

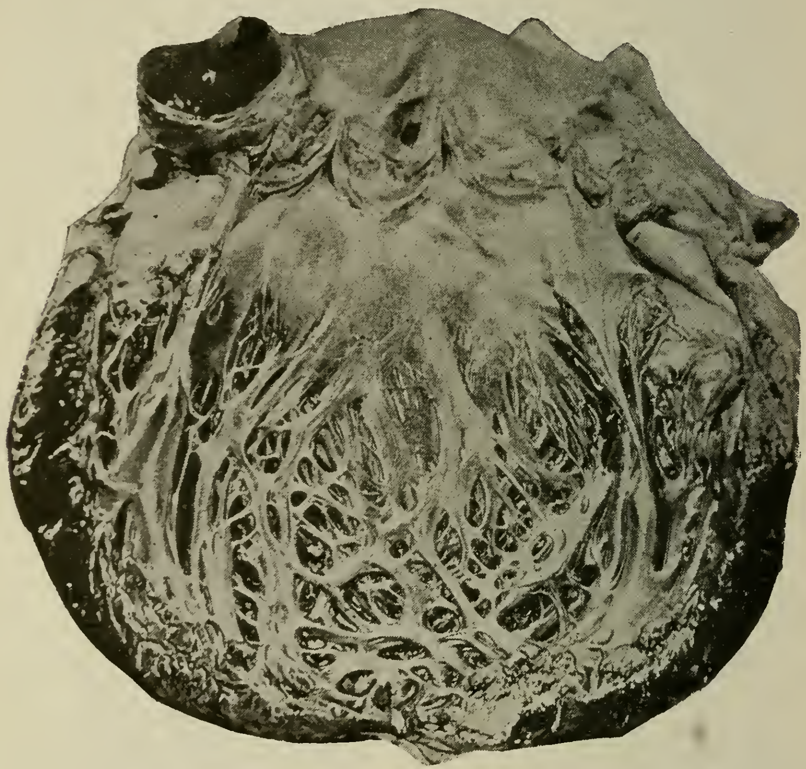


Fig. 19.—View of the Interior of the Left Ventricle of the Human Heart.

The ventricle has been opened through its anterior wall between the two papillary muscles from the apex through the aortic opening. Each side is hooked back and there appears the aortic wall above laid open—separating this from the ventricular cavity are the three semilunar valves. At the upper left corner is the opening of the pulmonary artery. Attached to the tips of the papillary muscles on each side of the ventricular cavity are the cordæ tendineæ, uniting to these muscles the large flaps of the auriculoventricular valves seen just beneath the aortic opening.

Because of the shape of each pocket, these valves are called semilunar valves. When closed, the three nodules come together at their center and by their free margins. Their edges are lined with delicate endothelium, and when coapted form three lines radiating from the center. The entrances of the veins into the auricles is guarded by encircling muscular fibers, which contract around the

opening of the veins when the auricles contract and thus prevent the blood passing back into the veins.

The main cavity of the right auricle is called the sinus venosus, or the atrium; a smaller cavity comes off from this anteriorly; it

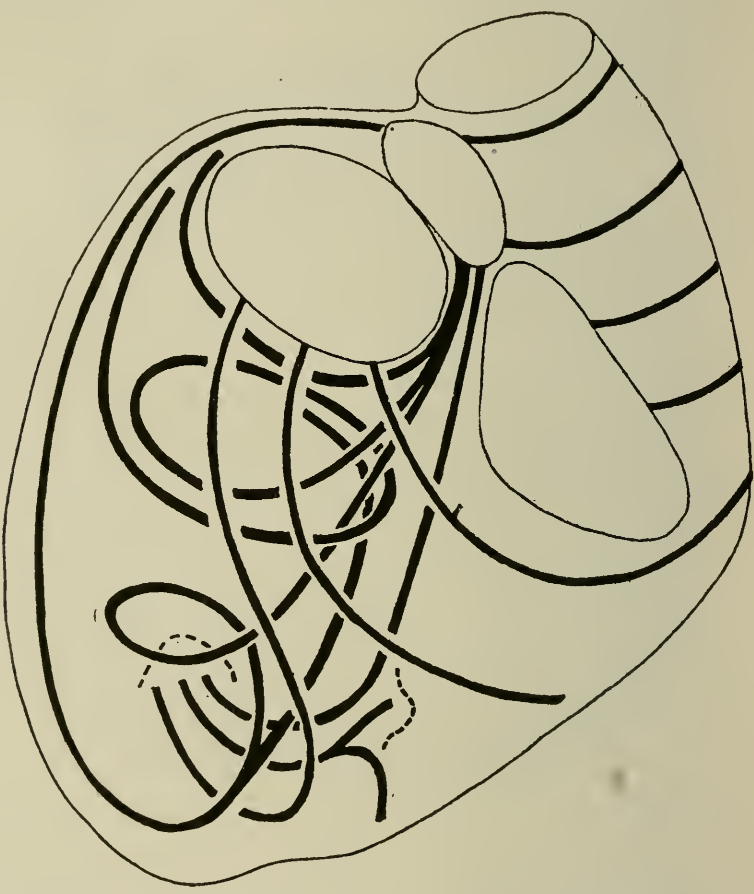


Fig. 20.—Diagram to Illustrate the Direction of the Chief Muscular Bundles of the Heart Seen from Behind.

The two auriculoventricular openings appear above in the foreground, with the opening for pulmonary artery and aorta behind. The sinospiral fibers are seen arising from the left auriculoventricular opening and sweeping around to the right around the right ventricle, while the bulbospiral sweep from the auriculoventricular ring in the region of the septum to the left, forming spiral turns around the ventricle, ending around the base of the aorta.

is called the auricular appendix. Anterior to the opening of the inferior vena cava, a crescentic fold passes from above the caval opening to the inner wall of the auricle. There it terminates in relation with a shallow inner wall of the auricle, where it is in

relation with a shallow depression, the fossa ovalis. The fold is called the Eustachian valve.

During fetal life the fossa ovalis was a foramen, the foramen ovalis. It served to allow the passage of the blood from the right auricle directly to the left auricle, a short circuit, in other words, around the lungs, for which organs the fetus has no use.

Between the opening of the superior and inferior vena cava is

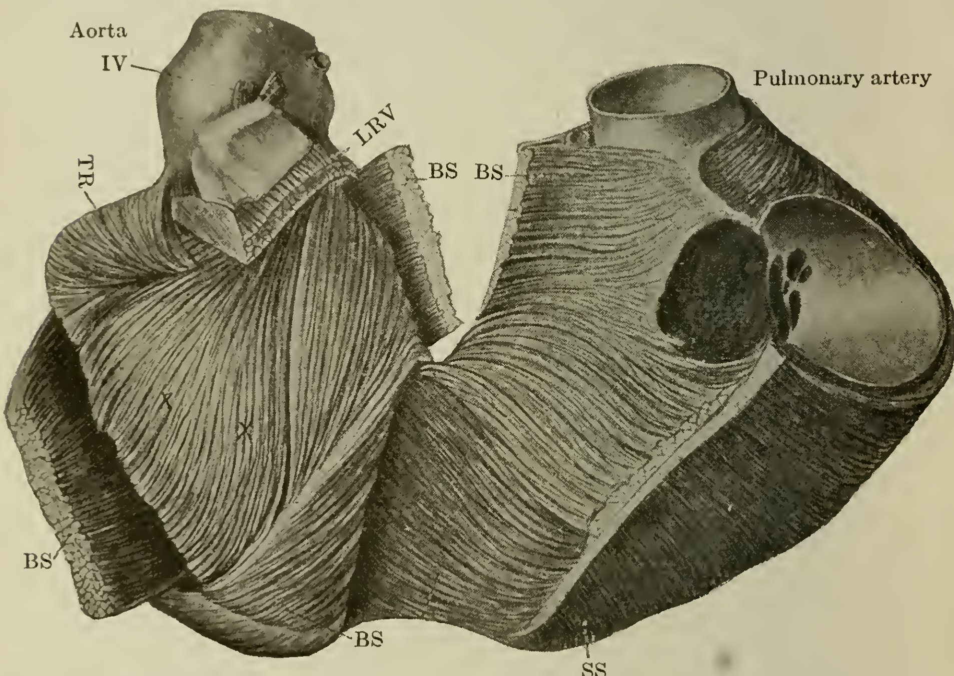


Fig. 21.—Interior Musculature of the Heart with the Septum Completely Divided.

BS and BS, superficial and deep bulbospiral bands; SS, sinospiral fibers; IV, interpapillary band; LRV, origin of the longitudinal bundle of the right ventricle which entered the hole torn in the right ventricle; TR, posterior triangular field; X, termination of the bulbospiral bands. (Franklin P. Mall.)

quite an elevation, the tubercle of Lower. Between the opening of the inferior vena cava and the right auriculo-ventricular opening is the coronary sinus. Into it open the coronary veins. The coronary sinus is guarded by a vestigial valve, the valve of Thebesius.

The right ventricle is somewhat crescentic in shape on cross-section. Its cavity is prolonged upward into the pulmonary artery. This cone-shaped prolongation is called the infundibulum, or the conus arteriosus; within the ventricle muscular ridges and a papillary elevation project from the walls.

These ridges are called columnæ carneæ. Instead of forming ridges, these bands may be attached at both ends only. The papillary elevations are called musculi papillares; the right ventricle contains three and the left two large ones. To their free end the chordæ tendineæ are attached. They hold down the free edge of the auriculo-ventricular valves.

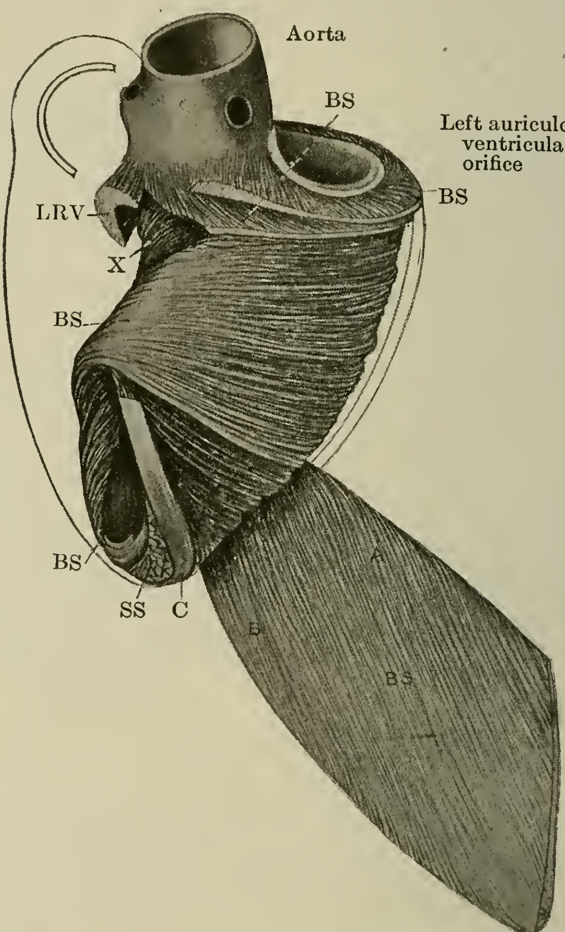


FIG. 22.—SAME VIEW AS FIG. 21, WITH THE SUPERFICIAL BULBOSPIRAL BAND THROWN BACK AND THE DEEP BULBOSPIRAL BAND EXPOSED ENTIRELY.

The origin of these two bundles is shown, BS and BS, at the base of the heart; C, a strand of the bulbospiral band not turned back; LRV, longitudinal bundle of the right ventricle. The course of the bulbospiral band is marked BS. It ends at X. (Franklin P. Mall.)

The special features of the right auricle are the openings of the four pulmonary veins. The left ventricle differs from the right in that a cross-section of its cavity is circular and its muscular walls are much thicker.

The Heart Muscle—The muscular layers of the heart form, roughly, a superficial and a deep set. (Figs. 20, 21 and 22.) Each of these may be divided into a set belonging chiefly to the right, the sinospiral group, and another to the left ventricle, the bulbospiral group. The superficial fibers arise from the tendinous structure

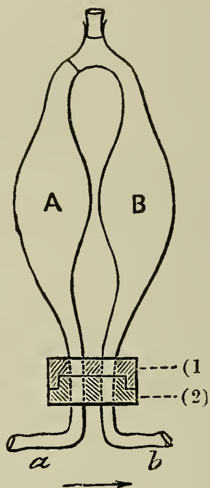


FIG. 23.—LUDWIG'S STROMUHR.

Two bulbs, A and B, fixed to the upper metal disk (1); two cannulæ, *a, b,* fixed to the lower metal disk (2); the upper disk movable round the lower, so that the connection between the bulbs A B and the cannulæ *a* and *b* can be reversed or interrupted. Cannula *a* fixed in central end of carotid, cannula *b* in peripheral end. Bulb A first filled with oil, bulb B with defibrinated blood. Blood from the central end of artery enters A, and drives by means of the oil the blood in B into the peripheral end of artery. A being full of fresh blood, B is full of oil: the position of the bulbs is suddenly reversed by a half revolution of the upper disk. B (full of oil) is now connected with *a;* A (full of blood) is connected with *b*. The maneuver is repeated several times.

Given the capacity of a bulb, the number of times it has filled and emptied, and the sectional area of the artery, the velocity of the blood current is calculated: e.g., a stromuhr placed on a carotid artery of a small dog showed a flow of 90 cc. per minute, i.e., 1.5 cc. per second. The sectional area of the vessel was 5 square mm., i.e., 1/20 square cm. The rapidity of the current is, then, 1.5 divided by 1/20, i.e., 30 cm. per second. (Waller.)

of the auriculo-ventricular ring, pass obliquely down on the superficial surface of the right or left ventricle, forming, especially in the case of those belonging to the left ventricle, spiral turns around the regions of the apex of the ventricle, and then turn upwards to end in the interventricular septum, or the papillary muscles.

The deep fibers are mostly circular, surrounding the ventricles.

Many of them lie between the superficial and deeper portions of the superficial fibers. Those of the left side arise mostly from the base of the aorta. Those of the right side surround the conus arteriosus, and both are attached to the auriculo-ventricular ring.

The auricular muscular fibers are continuous over both auricles

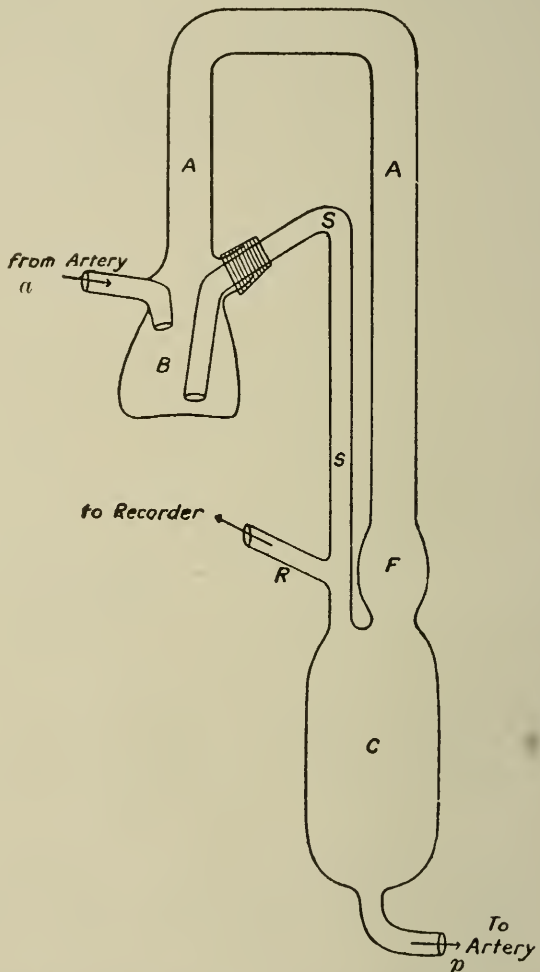


Fig. 24.—A Simple Blood Current Measure. (Starling.)

When B and tube A fill high enough to overflow through S, the larger limb S quickly empties the bulb B, so that it is merely necessary to count the number of times B empties per minute to know the rate of flow.

and ventricular fibers over both ventricles. The auriculo-ventricular ring forms a well-marked division between the auricles and ventricles. Nevertheless, a very important band of fibers, the bundle of His, forms a muscular bridge between the auricles and ventricles. It arises in the wall of the right auricle, passes beneath

the foramen ovalis across the auriculo-ventricular juncture, to end in the interventricular septum. Provision is thus made for simultaneous contraction of both auricles and ventricles and also for propagation of impulse along a band of muscle from the auricle to the ventricle.

The Pericardium—Surrounding the whole heart is a strong sac called the pericardium. It is continuous above with the large vessels at the base of the heart and lined internally with endothelium. It possesses a definite function in controlling the degree of filling of the heart during diastole. This function can be demonstrated by opening the sac and noticing the bulging of the ventricular wall through it each time the ventricle is filled by the contraction of the auricles, provided the rate of the heart is not too rapid.

The Velocity of the Blood—The velocity of the blood is measured by counting the number of times that it will take to empty and fill stromuhrs of various shapes which are inserted in the course of arteries. (Figs. 23 and 24). Variations in its velocity may also be recorded from a delicate tambour, the lever of which is operated by a fan moved by the current. They may also be recorded by photographing the difference in the height of two columns of blood within two tubes inserted at a short distance from each other in the course of an artery. The first tube receives the blood current directly, while the second is placed at right angles to the current. During systole the velocity of the blood is greater than during diastole. In the carotid of the horse during systole it is 520 mm. per second and during diastole it is 150 mm. per second. The following table has been prepared from experiments on the dog:

BODY WEIGHT.	ARTERY	VOL. PER SEC.	LINEAR VELOCITY PER SEC.	DIAMETER OF ART.	B. P.	NERVES.
	crural	0.63 cc.	128 mm.	2.5 mm.	77 mm.	uncut
14.6 kilo gr.	crural	1.69 cc.	275 mm.	2.8 mm.	88 mm.	cut
14.1 kilo gr.	carotid	1.95 cc.	241 mm.	3.3 mm.	93 mm.	uncut

In the large arteries of the human body the velocity of the blood is 1.5 meter per second.

The Cardiac Cycle—In general the cardiac cycle consists of a simultaneous contraction of both auricles lasting about .1 of a second. This is followed by a contraction of the ventricles, during

which the auriculo-ventricular valves are closed and the blood which had been forced into the ventricles by the auricular contraction now overcomes the pressure of the semilunar valves and enters the pulmonary artery and the aorta. The closure of the auriculo-ventricular valves and muscular contraction of the ventricles produces the first heart sound. This period occupies almost .25 second.

The ventricles then relax and the semilunar valves immediately close, producing the second sound. The ventricle then remains uncontracted for .4 second. During .3 of a second of this period the whole heart will be at rest.

The Cardiac Cycle in Detail as Studied by Tracings Taken with an Accurate Manometer—In order to understand the events occurring in the cardiac cycle and their time relations, it is neces-

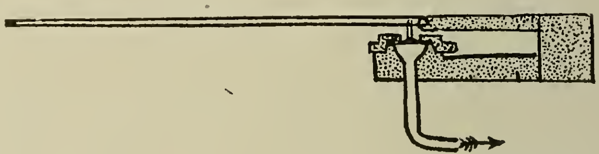


Fig. 25.—Diagram to Show Construction of Hurthle's Membrane Manometer. (Starling.)

sary to reproduce them graphically that the time relations and character of the cardiac contractions may be accurately recorded.

The very rapid changes of pressure within a heart cannot be recorded by a mercury manometer. The inertia of mercury is too great to respond with sufficient rapidity. The pressure must be transmitted to a strong rubber membrane (Fig. 25), the movements of which may be recorded by a writing lever through a reducer to a more delicate tambour as in Hurthle's manometer (Fig. 26) or photographically by a reflected ray of light, as in the manometer of Otto Frank or Piper.

Tracings must also be taken simultaneously from the ventricle and aorta. (Figs. 27 and 28.) When these are thus taken upon an animal and compared to the events recorded by a cardiometer applied to a human heart the variations of pressure of the cardiac cycle, together with their explanations, are as follows (Figs. 29 and 30):

1. A rise of pressure in both ventricles and auricles lasting 0.1 of a second and due to the auricular contraction. Depending

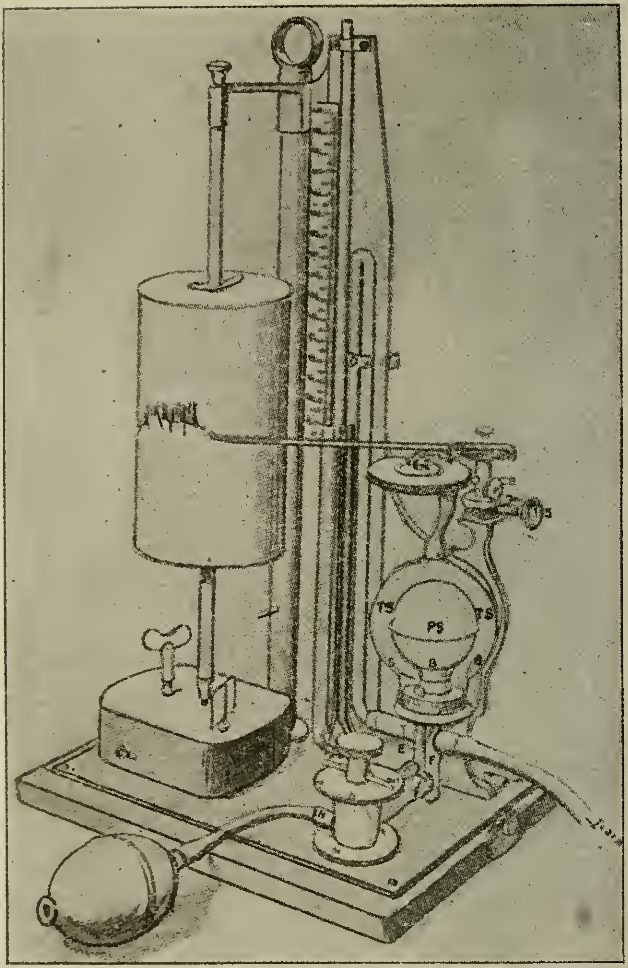


FIG. 26.—ERLANGER'S APPARATUS FOR RECORDING SYSTOLIC AND DIASTOLIC BLOOD PRESSURE. (Starling.)

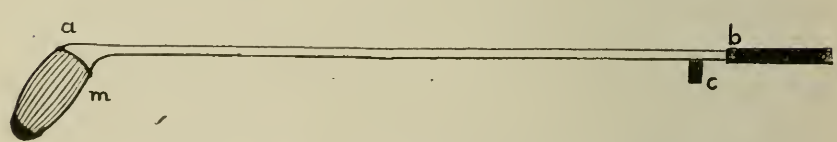


FIG. 27.—DIAGRAM OF MAREY'S CARDIAC "SOUND."

Consisting of a long tube *a b*, terminating at one end in the ampulla *m*, which is covered with an elastic membrane. The side piece *c* serves to indicate the position of the ampulla after it has been introduced into the vessels. (Starling.)

upon eddies which are created in the ventricles, the auriculo-ventricular valves become placed in a position midway between a closed and wide open position, in other words, in a position to close very quickly.

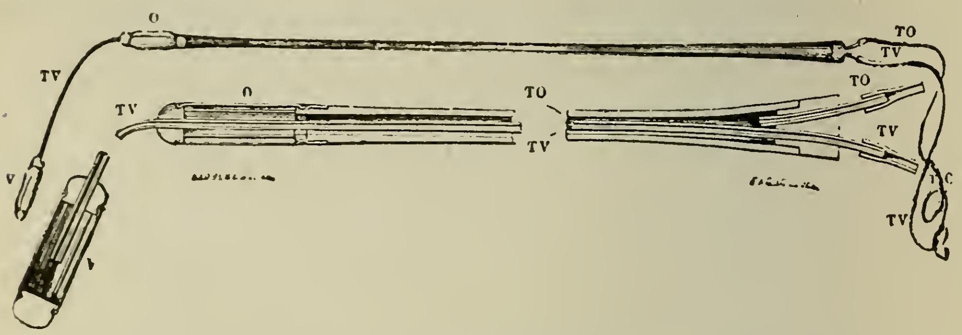


FIG. 28.—INTRACARDIAC SOUND FOR TAKING TRACINGS OF INTRACARDIAC BLOOD PRESSURE.

The rubber cover is protected from the high pressure by steel springs. (E. J. Marey.)

2. A very rapid rise of pressure in both ventricle and auricle caused by systole of the ventricle. (Fig. 31). The rise of the pressure lasts longer in the ventricle than in the auricle, inasmuch as the rise of pressure in the auricle ceases as soon as the auriculo-ven-

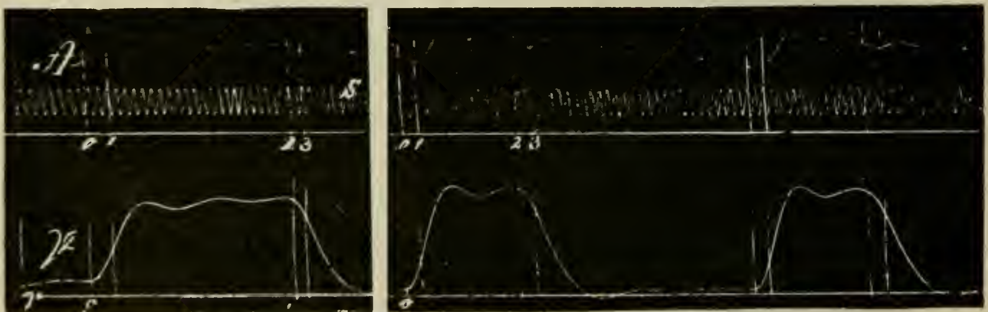


FIG. 29.—SIMULTANEOUS CURVES OF THE BLOOD PRESSURE IN THE AORTA (A) AND LEFT VENTRICLE (V).

a, Normally acting heart; *b*, a heart quickened by excitement.

tricular valves encroach no further after their closure upon the auricular cavity. The first .02 to .04 of a second of this sudden rise in ventricular pressure is occupied by overcoming the resistance of the aortic valves. Synchronously with the opening of these valves, the rise of pressure in the auricles ceases. The pressure in the auricles

immediately sinks for another .1 of a second. It then gradually rises again, due to the filling of the auricles with blood returned through the veins. In the meantime the pressure continues to rise in the ventricle for another .04 of a second and remains at its maximum height for about .18 of a second.

3. During this period it shows two secondary minor variations

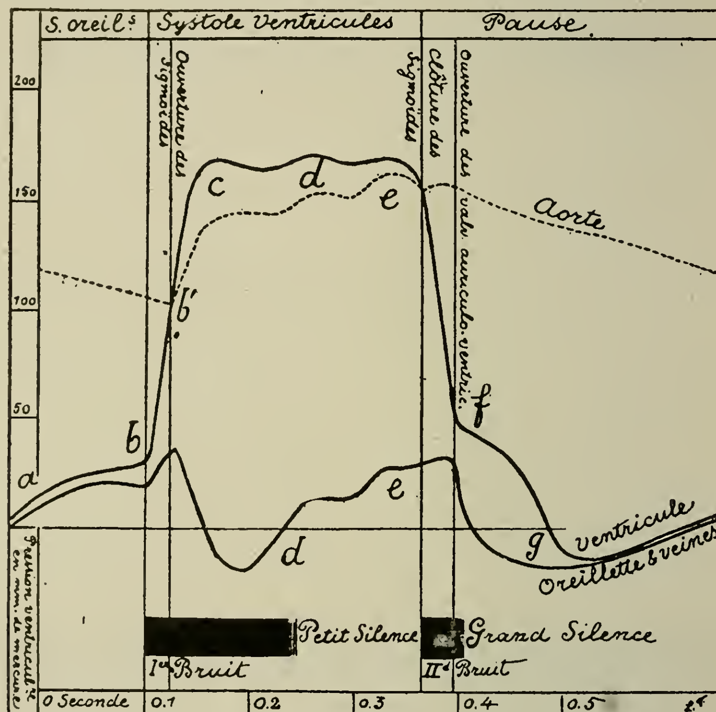


FIG. 30.—DIAGRAM ILLUSTRATING THE VARIATIONS OF PRESSURE IN THE VENTRICLE, IN THE AURICLE AND IN THE SUPERIOR VENA CAVA DURING ONE CARDIAC CYCLE OF A DOG.

a b, Systole of the auricle; *b c d e,* systole of the ventricle; *b′*, opening of the aortic valves; *e,* closure of the aortic valves; *b b′*, closure of the auriculoventricular valves; *f*, opening of the auriculoventricular valves; *f g,* postsystolic emptying of the auricles and filling of the ventricles. The absolute duration of these divisions of the cycle and the period occupied by the heart sounds are indicated below, and the absolute height of the aortic and ventricular blood pressure is indicated to the left. (Léon, Tredericq, *Arclio. International de physiologi.*)

in pressure, due to shooting out of the blood into the aorta and the oscillatory recoil of the heart. Then comes the period of relaxation of the ventricle, lasting .05 of a second, and the immediate closure of the aortic valves.

4. As soon as the ventricles are relaxed the pressure within

them is less than in the auricles, so that blood begins to flow from the auricles into the ventricles. This causes a rapid fall of the auricular pressure which had been raised by the entrance of blood into the auricles from the veins.

5. After .1 of a second more the cavities of the ventricle and auricle become filled with blood, and though both the ventricle and auricle remain relaxed for a much longer time, .3 of a second, the pressure slowly rises in the ventricle as well as in the auricle from the continued return of blood through the veins. A sum of these various periods, .1 plus .03, plus .04, plus .18, plus .05, plus .1, plus

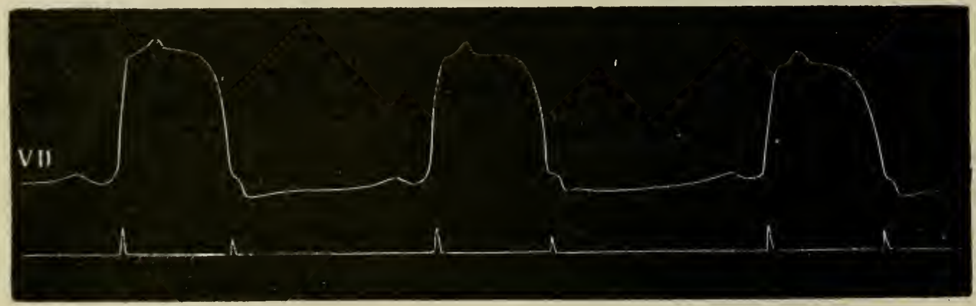


Fig. 31.—Tracing of the Intraventricular Pressure of a Horse.

On the base line the signals indicate the time of the first and second sounds. (E. J. Marey.)

.3 equals .8 of one second, the total period of the cardiac cycle. Of this time the auricular systole lasts .1 of a second and the ventricular systole lasts .3. The auricles are at rest for .7 of a second and the ventricles for .5 of a second. The whole heart is resting at the same time for .4 of a second. Thus the period at which the heart is at rest is much longer than when it is active.

When the heart action quickens it does so at the expense chiefly of diastole. Thus the pulse may vary from 32 to 124 (4×32) times a minute. The duration of systole for these extremes is .382 (2×190) of a second in the one case and .190 of a second in the second case. While then the pulse has increased four times in frequency, the systolic period has shortened only one-half.

Inasmuch as the great veins possess no valves where they enter the heart but depend upon the constriction of the cardiac muscle around their orifices for protection against the intracardiac pressure, the variations in pressure within the auricles are to a rather large degree transmitted to the veins. For each heart beat the

large veins pulsate twice. They feel the two periods of increase in the auricular pressure due to the auricular and ventricular systole.

Shape of the Heart—Changes in shape of the heart during contraction and in its relation to the chest wall:

During diastole the heart muscle is perfectly flaccid, and its shape will depend much upon the force of gravity. Inasmuch as it rests upon the anterior slope of the diaphragm, it will be flattened from before backwards and from above downwards.

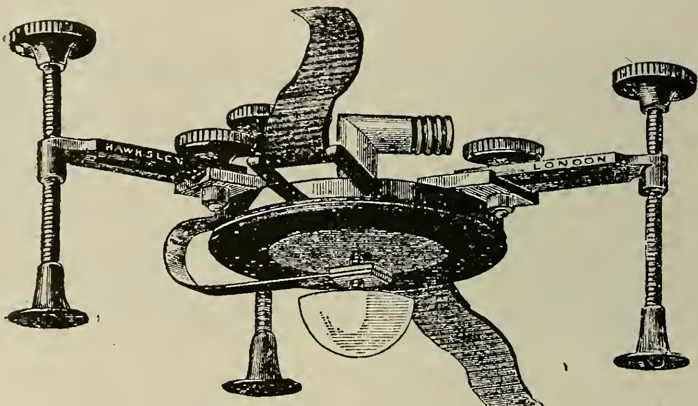


FIG. 32.—A CARDIOGRAPH.

This is strapped round the chest, the central button is applied to the "apex-beat" and its pressure on the chest wall regulated by means of the three screws at the sides. The tube at the upper part of the instrument serves to connect the drum of the cardiograph with a registering tambour such as that shown in Fig. 33. (Starling.)

Systole

During contraction the whole heart becomes rounder in its cross-section. The transverse diameter diminishes and the anterior diameter increases.

The pericardial cavity preserves the contour of the heart, and inasmuch as the pericardium is attached to the diaphragm below the apex of the heart, it is prevented from moving upwards during contraction. It will remain fixed and the base will move toward the apex. This movement can be demonstrated by passing needles through the chest wall and into the heart at its base and into the ventricle, midway between the base and apex and into the apex. During contraction the extremity of the needles external to the chest wall will indicate the movement of the base toward the apex. Neither the cavity of the right or left ventricle entirely empty themselves during systole.

Apex-Beat—Its Cause—During systole of the heart an impulse is imparted to the chest wall which can be felt in the fifth intercostal space. This impulse is generally spoken of as the apex-beat, and formerly was supposed to be caused by the apex of the heart pushing itself against the chest wall during systole.

As a matter of fact, the apex of the heart is both much lower than the fifth intercostal space and is just that portion of the heart which does not move during contraction. The impulse in the fifth space called the apex-beat is due to the anterior wall of the heart pushing against the chest wall; the antero-posterior diameter lengthens and the lateral diameter shortens in consequence of the

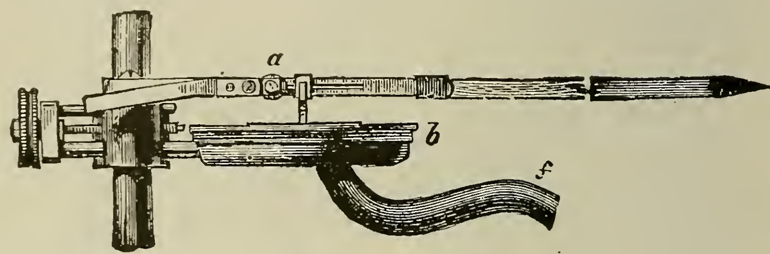


Fig. 33.—Marey's Tambour.

a, Axis of lever; *b*, metal tray covered with rubber membrane, and communicating by tube *f* with free end of cardiac sound. (Starling.)

change in shape of the heart to the cylindrical form during contraction.

The Cardiometer and the Character of Its Tracings—It is possible to produce a tracing from the apex-beat which will record graphically the changes transpiring in the ventricles. An instrument for this purpose is called a cardiograph. It consists simply of a button which moves a tambour in series with a second tambour and a writing lever. (Figs. 32 and 33.) Such a tracing shows in general curves with the same characters as tracing of the intraventricular pressures. There is first a small elevation, indicating the auricular contraction, followed by the systolic wave, which slowly declines during the period of the systolic plateau until the period of relaxation of the ventricle. There is then a very rapid decline, after which the curve slowly rises again as the ventricle becomes filled with blood. (Fig. 34.)

The Three Heart Sounds—Each cardiac cycle is accompanied with two very distinctly heard sounds and a third sound described by many observers.

The relation of these sounds to the various events of the cardiac cycle can be easily studied by marking the time of their occurrence upon the tracings of the cardiac cycle. (Fig. 35.)

The first sound is a low-pitched, prolonged sound, expressed well by the word lubb. It is synchronous with the rise of pressure in the ventricles, and depends upon two causes. One of these is the closure of the auriculo-ventricular valves and the other is the muscular contraction of the walls of the ventricles. The two elements in the production of the first sound are demonstrated by the change and not the disappearance of the first sound when the large veins entering the heart are clamped so as to render closure of the auriculo-ventricular valves impossible. The first sound is heard most distinctly over the site of the apex-beat.

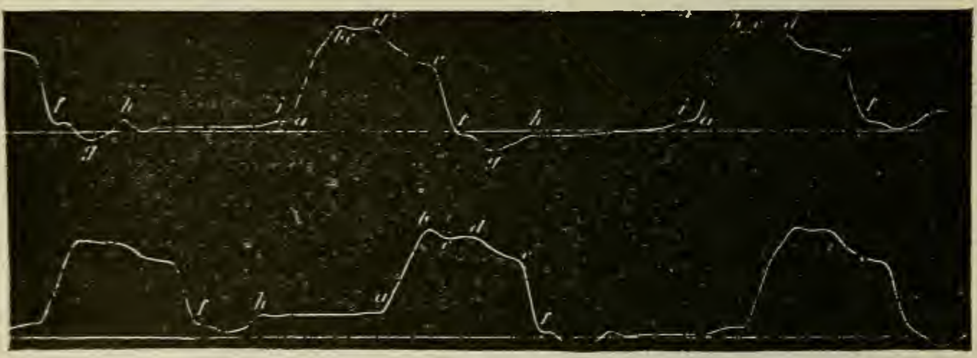


Fig. 34.—Cardiometer Tracing of the Normal Heart.

The second sound is caused by the snap back of the aorta and pulmonary valves. Hooking back these valves will cause its disappearance. Sometimes the aortic and pulmonary valves will not close quite simultaneously; we then have a reduplication of the second sound. The second sound is shorter and higher pitched than the first. It is usually imitated by the word dub. The second sound is loudest over the second right costal cartilage.

The pulmonary element is loudest over the second left costal cartilage. The third sound is difficult to hear. It is low pitched and soft. It should be listened for over the apex. It occurs a short time after the second sound during the beginning of diastole. It is caused by the first inrush of blood during diastole into the ventricles and depends upon vibrations set up in the fluid itself.

Whenever complete closure of any of the valves of the heart is

impossible because of disease which may have deformed the valves or thickened them or dilated the orifice, or whenever the orifice is contracted or changed by the production of a nodular thickening around it, vibrations will be set up in the blood as it passes through the orifices, which will give rise to a blowing bruit in place of the normal heart sound that should occur at that time in the cardiac cycle.

The Factors Responsible for the Return of Blood to the Heart —The mechanism by which the heart is filled during diastole is important. It is entirely upon the possibility of the blood flowing

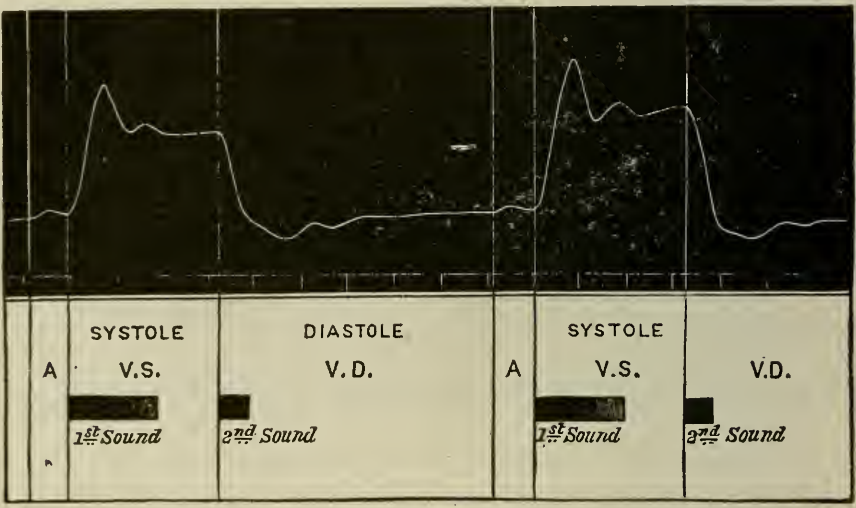


FIG. 35.—A TRACING FROM THE "APEX-BEAT" OF MAN.

Relation of sounds to contraction indicated below the tracing by black marks. (Waller.)

from the veins into the auricles that the circulation can be maintained at all. The output of the heart depends upon the quantity of blood returned to it during diastole by the large veins and, therefore, upon the pressure within these veins. With a moderate and constant return to the heart an increased arterial pressure or increased rate of heart beat does not alter the output, whereas the output of the heart is at once increased or diminished by similar changes in the venous inflow so long as the heart remains functionally capable of dealing with the increased demands upon it. The venous pressure is with these qualifications an index to the output of the heart, and there is an optimum venous pressure. Notwithstanding the relatively shorter diastole accompanying an increased

heart rate, an increase in the rate of the heart will enable the heart to deal more efficiently with maximum venous pressure, in other words, to receive and therefore expel more blood than at slower rates. The flow of blood from the veins into the auricles alone depends upon the existence of a progressive diminution of pressure between the capillaries and the auricles. The pressure within the great veins depends in turn upon the following factors:

1. Upon the blood pressure transmitted through the capillaries into the venules.
2. The position of the body.
3. The existence of valves within the veins making effectual the pressure exerted on the walls of the veins by the muscles of the body during their contraction.
4. The existence of a negative pressure within the thorax resulting from respiration.

The pressure changes in the chest are so extensive that they are quite as important as the other two causes of the return of the blood to the heart. Natural expiration is accomplished by the retraction of the lungs within the chest cavity solely as a result of their own elasticity. This retraction produces a negative pressure within the thorax at the end of expiration of 5 mm. at the end of inspiration of 9 mm. Although in forced expiration there may be an actual positive pressure created within the chest cavity, yet in forced inspiration the intrathoracic negative pressure is greatly increased. These respiratory movements produce, therefore, a pumping action upon the large veins, the walls of which are so flaccid that they readily transmit the intrathoracic pressure through them to the blood. At the end of each inspiration there is an increased flow into or storage of blood in the great veins. At the end of expiration this flow is diminished, but there is an increase in the pressure tending to drive the blood into the heart.

In extreme muscular exertions with the glottis closed a constant positive pressure may exist in the thorax which is capable of altogether stopping the return of blood to the heart. It is possible to stop the pulse at the wrist by experiments of this kind.

The Cardiopneumatic Movements—The heart in its turn also effects the intrathoracic pressures. Contracting at each systole, the space within the chest which it occupies is smaller, and consequently a diminution of the intrathoracic pressure results. These

cardiac variations of the intrathoracic pressure may be recorded in tracings of the respiratory movements taken from a delicate tambour attached to the nostril. They are called the cardiopneu-

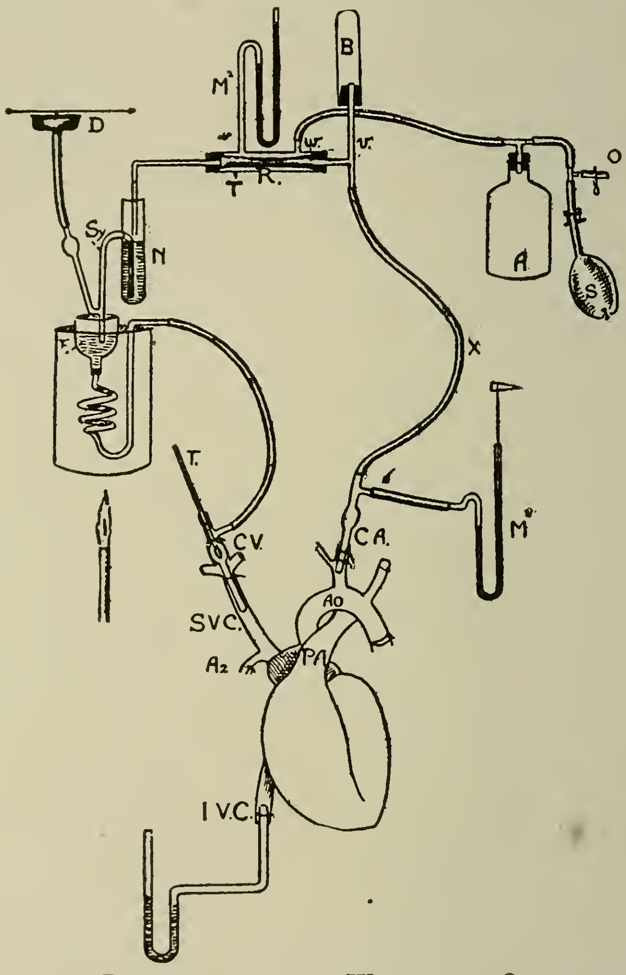


Fig. 36.—Device for Determining the Work and Output of the Heart. Cannulæ are placed in the innominate artery and superior vena cava. Between these two vessels the blood mixed with hirudin circulates at a pressure measured by the manometer, M, through the peripheral resistance, R, which can be varied by the air bulb S. The inverted air chamber, B, replaces the elasticity of the arterial walls. The blood then flows at low pressure into N. The siphon tube S can be so arranged that 10-30 cc. can be siphoned off at regular intervals. The blood is returned to the heart from the reservoir F in which it is warmed.

matic movements. Any increased pericardial pressure diminishes the return of blood to the heart and, therefore, embarrasses the heart's action.

The Output of the Heart and Its Estimation—By a number of ingenious devices (Fig. 36) it has been possible to create an artifi-

cial circulation, using the normally beating heart as the pump, and not only registering the pressure, but also the output. These devices are called cardiometers. Another type of these same instruments incloses the heart and records the variations of air pressures produced by the cardiac contractions within the inclosing sphere and thus measures the output per beat.

As a result of experiments with these instruments the output of the right or left ventricle, for they are both equal, is from 50 to 100 c. c. at each beat. Its average output may be said to be 60 c. c.

The Work of the Heart—If the average output of the heart is 60 cc. and if the average pressure against which the heart pumps is 100 mm. of Hg. and if the velocity in the aorta during systole is 500 mm. a second, the work done by the heart during the brief period of ventricular contraction of a little less than .3 of a second would be 60 by 0.100 by 13.6, equal 81.6 grammeters. This figure neglects the factor of varying resistance in the aorta and the additional energy required to get up speed in the aorta. Both these factors are small and may be neglected. The work done in the right ventricle at each beat is 16 grammeters, the pressure in the pulmonary artery being 20 mm. of Hg.

The work for both ventricles is 100 grammeters per beat, or 10,111 kilogrammeters in 24 hours. Inasmuch as the heart wall must contract upon a larger volume and is thinner at the beginning of systole than at the end, the amount of work done at the beginning of cardiac contraction is greater than at the end. Therefore, unrestricted diastolic filling of the heart is not an unqualified advantage.

THE PULSE

The Cause of the Pulse Wave—An impulse imparted to an incompressible fluid at one end of a rigid tube is instantly propagated from one molecule to another to the opposite end of the tube. If the tube were filled with compressible gas, as, for instance, air, an appreciable length of time would be occupied in the transmission of the impulse from one end of the tube to the other.

If an impulse is imparted to an incompressible fluid contained in an elastic tube an appreciable length of time is also required for the transmission of the impulse through the length of the tube.

This is true because the force of the impulse transmitted to the fluid is expended equally in all directions and part is spent in the distention of the walls of the tube. That part which is propagated forwards is resisted at first by the column of fluid in front, but finally accelerated by the recoil of the elastic walls of the tube, so producing an exactly similar effect upon a more distal segment

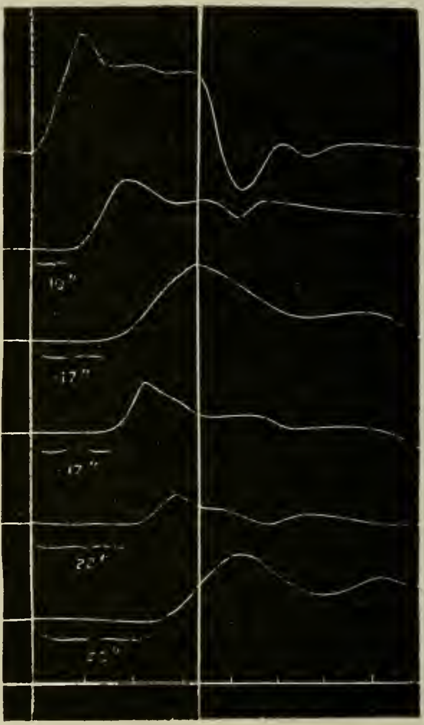


Fig. 37.—Illustrating the Pulse Waves in the Arterial System. (Waller.)

Made by taking simultaneous tracings in the various arteries from above down as follows: 1, The heart; 2, the carotid; 3, the femoral; 4, radial; 5, the anterior tibial; 6, by a plethysmograph on the foot. Time = .1 sec.

of the tube. By this mechanism a wave is transmitted in the fluid from one end of the elastic fluid to the other.

The Velocity of the Pulse Wave—The wave of fluid caused in the arteries by the discharge of blood into them at each systole produces a wave in the arterial wall and is called the pulse. It is transmitted with a velocity of 7 meters a second. (Fig. 37.) The velocity of the transmission of a pulse wave is entirely different from the velocity of the flow of the blood. The two must not be confounded.

The Factors upon Which the Velocity Depends—The velocity of the pulse wave depends upon the following factors:

1. The acceleration due to gravity.
2. The elastic coefficient of the wall.
3. The thickness of the wall.
4. The diameter of the tube.
5. The density of the fluid.
6. The propelling force and a constant.

Its Length—The speed of a pulse wave is 7 to 10 meters a second. Its time in passing any one point corresponds to that of one cardiac cycle, namely .8 of a second. Its length would, therefore, be the product of these two numbers, i.e., 5.6 to 8 meters.

Factors Causing a Variation in the Character of the Pulse Wave—We may call the pulse wave above described the main positive wave. Any record of such a wave will be complicated by secondary waves. If, for instance, the end of an elastic tube transmitting a wave is closed at its distal end as soon as the wave reaches the end, it will be reflected back as a reflected wave and be nearer to the main positive pulse wave at points progressively nearer to the distal blocked portion of the tube. If the inrush of fluid into an elastic tube is suddenly stopped a negative secondary wave is started behind the on rushing fluid and travels the whole length of the tube. Similarly if the distal end of the elastic tube is opened the sudden outrush of the propelled fluid will cause a negative reflected wave, which is transmitted backwards through the whole length of the tube. In the human body reflected waves must take place at each division point of an artery, but these points are so multitudinous that all these various waves unquestionably neutralize each other.

Methods for Recording Pulse Waves—Instruments for recording pulse waves are called sphygmographs. As cardiometers for the heart they make their tracings upon a moving surface by a lever or ray of light which is moved by the oscillations of a tambour. (Fig. 38 A and B.)

The Character of a Typical Pulse Wave—A typical pulse tracing presents a rapid upward stroke and a slower downward stroke, the latter containing one main and not infrequently other secondary rises and falls. (Fig. 39.)

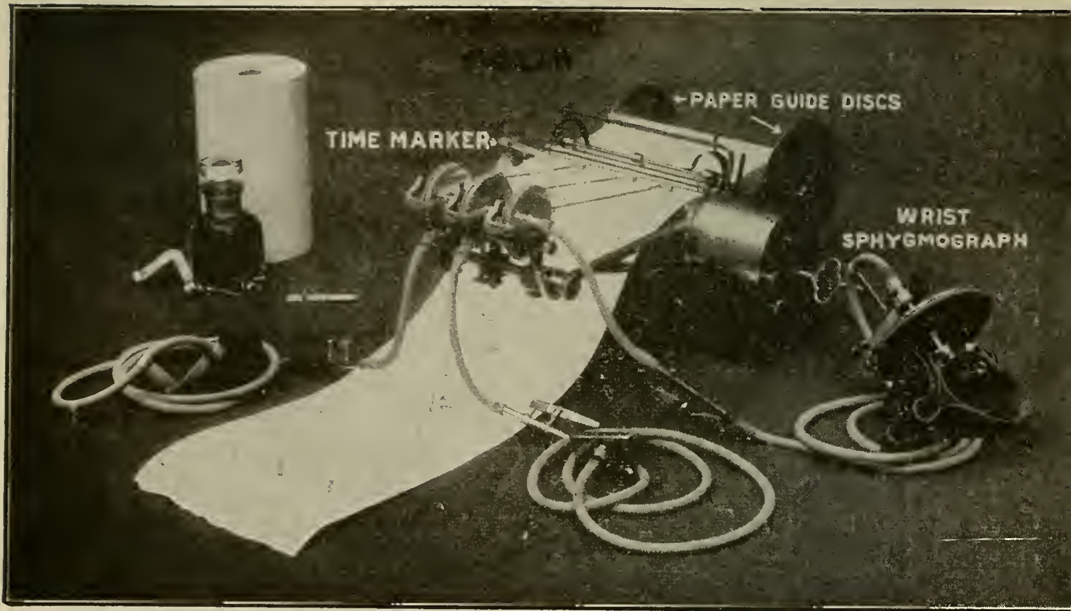


FIG 38A

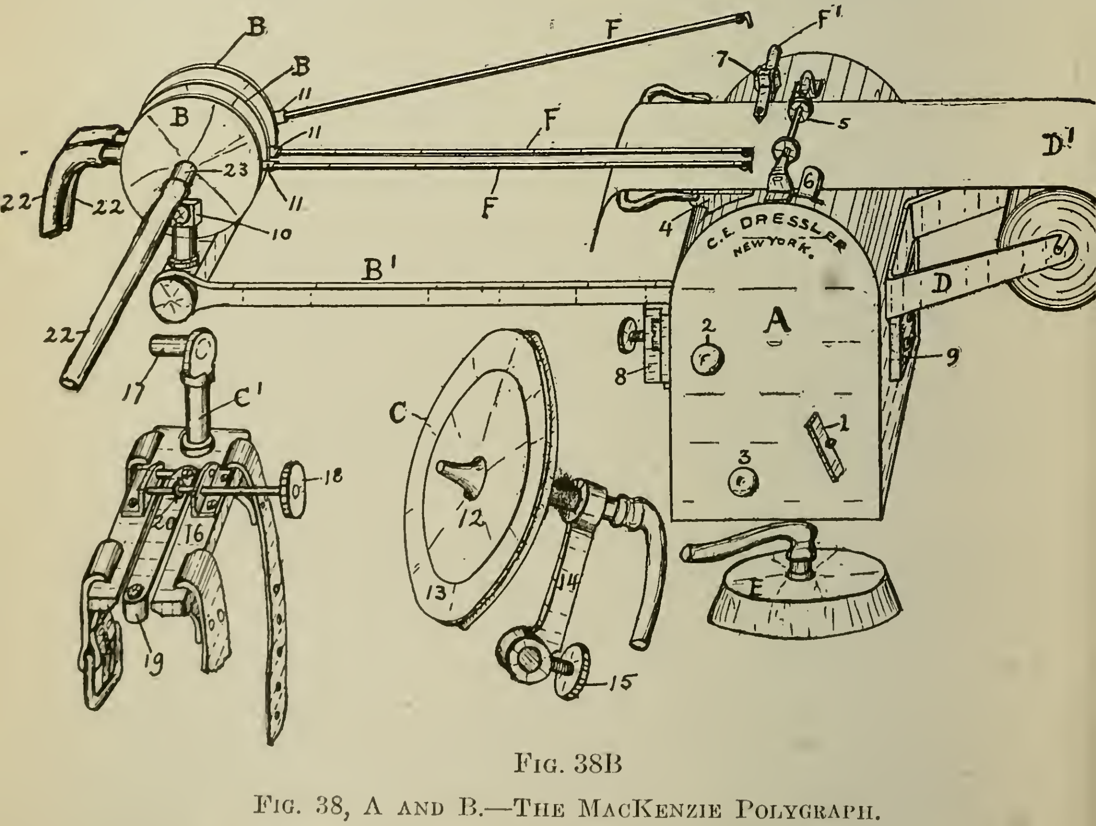


FIG. 38B

FIG. 38, A AND B.—THE MACKENZIE POLYGRAPH.

Upon the paper moved by clockwork are recorded in ink simultaneous tracings of the apex-beat, the radial pulse and the jugular pulse.

The first upward stroke corresponds to the emptying of the blood into the aorta by the systole of the heart. It is called the primary or percussion wave. At varying distances from the summit of this curve are the secondary undulations. The most important one of these is called the dicrotic wave, and the notch preceding the rise of this wave is called the dicrotic notch.

It coincides with the sudden relaxation of the ventricle and the closure of the aortic valves. It is, in other words, a negative wave transmitted peripherally and due to the sudden cessation of the onrush of blood. The dicrotic depression is immediately succeeded by an upward stroke, the dicrotic wave. This is a positive impulse started by the rebound of the fluid against the aortic waves.

Fig. 39.—Normal Pulse-Curve from Radial Artery. (Starling.)

In many pulse tracings two additional secondary waves are recorded, one immediately before and one immediately after the dicrotic notch. The one before the notch is called the predicrotic wave and the one after it the postdicrotic wave.

The predicrotic wave may be regarded as elastic oscillations set up in the arterial systems by the sudden rise of pressure, and the postdicrotic as similar oscillations set up by the dying away of the maximum pressure.

Factors Which Change the Character of a Typical Pulse Tracing—Both these pre- and postdicrotic waves are much increased by the distorting effects due to the fling of the recording mechanism.

The exact position on the pulse curves of these secondary waves, as also the height of the main elevations of a pulse, is much influenced by the strength of the heart beat and the pressure in the arteries. When the first set of secondary waves occur on the ascending curve of the primary pulse wave they are called anacrotic. When they occur entirely on the descending portion they are called catacrotic. (Fig. 40.)

When the peripheral resistance is high, blood will pass into the aorta under conditions of a rising aortic pressure during the whole

of the systole. Secondary oscillations in the pulse will then appear during a period of rise in pressure, i.e., on the upward curve of the pulse tracing, and the pulse will be anacrotic. When, however, the arteries are dilated and the peripheral pressure is low the pressure in the aorta may begin to fall before the systole is finished, the blood running out of the peripheral vessels faster than it is pumped in. Particularly when, as usually happens with a low

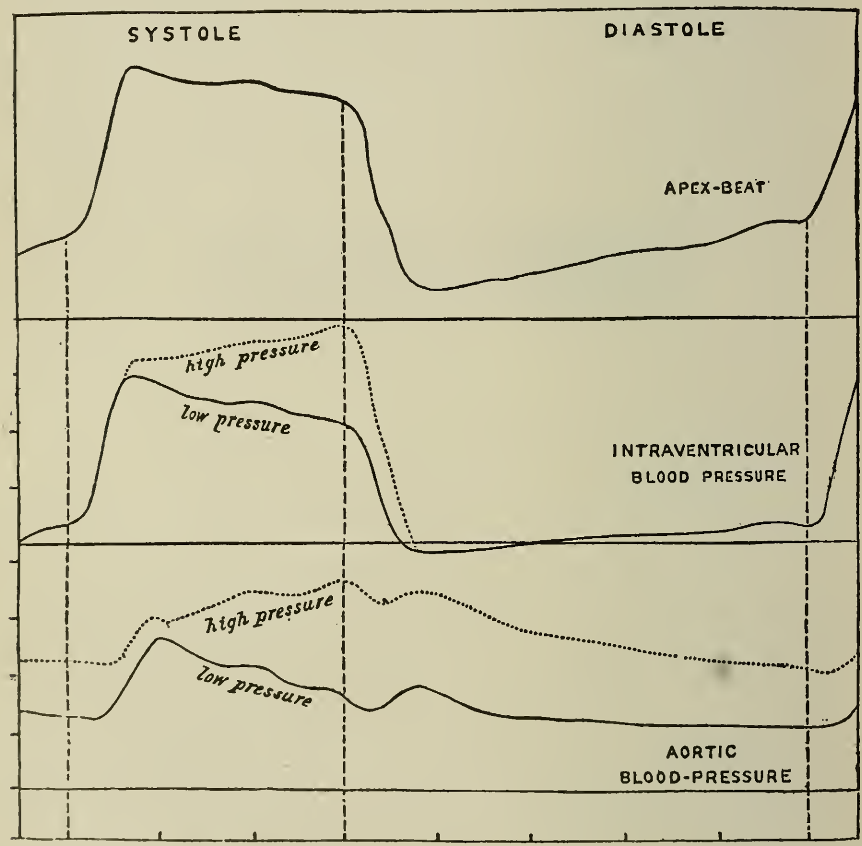


FIG. 40.—DIAGRAM AFTER HURTHLE (CONSTRUCTED FROM DIRECT OBSERVATIONS ON THE DOG) TO ILLUSTRATE SYSTOLIC AND DIASTOLIC PRESSURE-VARIATIONS OF THE VENTRICLE AND AORTA ON MAN.

The noteworthy points of the tracing are: The similarity between apex-beat and intraventricular pressure; the greater postsystolic negative pressure in the ventricle than in the aorta during systole; the unvarying duration of systole at high and at low blood-pressure; maintained pressure in the aorta; the negative pressure (diastolic notch) immediately followed by the diastolic wave. At "low pressure" the systolic pressure in the aorta is double the diastolic pressure; in the high-pressure curve (dotted lines) the difference is proportionally smaller, i.e., a systolic augmentation of 1/4 to 1/3 of the mean arterial pressure. Notice that the systolic pressure augments from beginning to end at high pressure, and falls from beginning to end at low pressure. The first tracing is a cardiometer tracing. (Waller.)

peripheral resistance, little blood is thrown at each systole into the aorta. Under these conditions the secondary oscillations will appear on the descending curve of the pulse wave.

No secondary vibrations independent of instrumental deformation occur within the heart during the period of endocardiac rise in pressure; neither is there a true systole plateau to the endocardiac pressure. In the aortic curve of blood pressure secondary oscillations appear at the first falling of the rapid rise of pressure. Then comes the dicrotic wave. Again at the end of the diastole a second set of oscillations appear, which represent the vibrations set up by the beginning of the ventricular contraction.

All these secondary vibrations diminish as the wave progresses to the periphery. Well-marked secondary oscillations in the aorta may be absent in the fermoral artery.

By accurate records of the pulse much information may be gained regarding the character of the circulation. This includes the force and frequency of the heart and strength of the heart beat, its output per beat and the blood pressure in the arteries. Even by feeling the pulse the changes in it which indicate these characters of the circulation may be appreciated.

The Different Varieties of Pulse—A pulse may vary, therefore in

1. Frequency; it may be rapid or slow.
2. Amplitude; it may be large or small.
3. Velocity; it may be characterized by a speedy or slow change of its excursions; it may thus be quick or leisurely.
4. Tension or pressure; it may be hard or soft.
5. Strength; it may be strong or weak.
6. Regularity; it may be regular or irregular.
7. Rhythm; it may be intermittent or regular.

When the peripheral tension is low and the heart strong, as in many fevers of long duration, the dicrotic wave is apt to be particularly well marked. The pulse may then be spoken of as dicrotic. (Figs. 41, 42 and 43.) When the force of the heart is unimpaired, but there is some injury to the aortic valves, allowing some of the blood to leak back into the heart during diastole, there

FIG. 41.—PULSE-TRACING BEFORE, A, AND AFTER, B, THE INHALATION OF NITRITE OF AMYL.

Tension diminished and frequency increased. The pulse is large and very soft, with fast rise and fall and marked dicrotic wave. (Waller.)

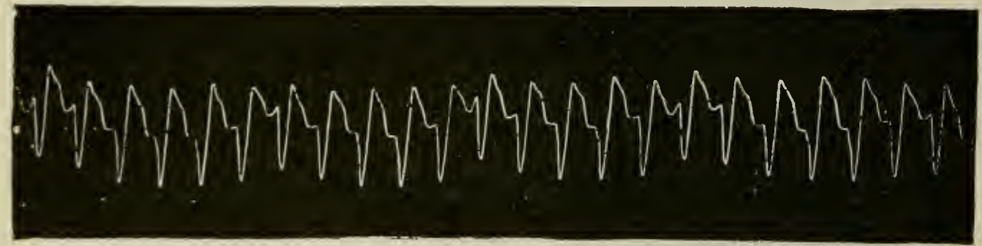


FIG. 42.—CAROTID PULSE-CURVE DURING CONVALESCENCE AFTER TYPHOID FEVER.

The pulse is large and soft with well-marked dicrotic wave.

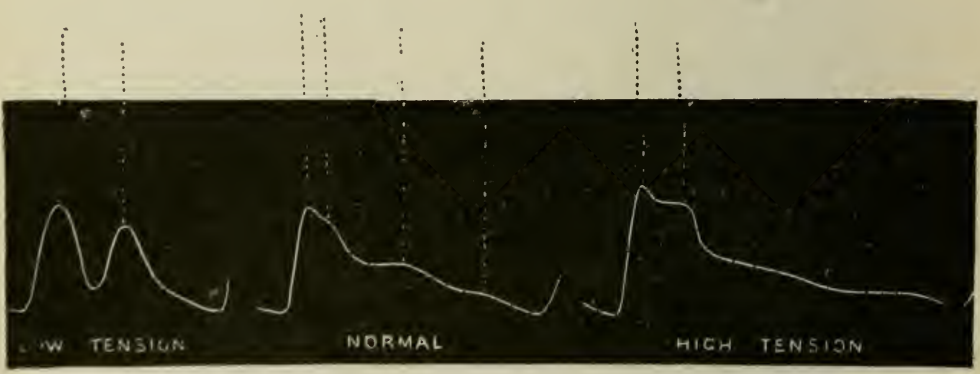


FIG. 43.—ILLUSTRATING THE DIFFERENT CHARACTER OF THE PULSE-WAVE UNDER VARYING CONDITIONS OF ARTERIAL BLOOD PRESSURE.

The characteristic features concern the character of the dicrotic wave.

will be a quick rise of pressure and a very rapid fall. Such a pulse is characteristic of the condition of the aortic valves. It is called the water hammer pulse.

PLETHORA AND ANEMIA

The Effect of Increasing the Total Volume of Blood by the Injection of Saline Fluid—The total volume of the blood may be increased by the injection of normal saline solution or of defibrinated blood or of the blood from another individual. When saline solution is used because dilution of the blood occurs the condition is called hydremic plethora.

The increase of the total volume of fluid in this manner does not increase materially the arterial blood pressure unless it has been much diminished as a result of hemorrhage.

Any increase in the arterial pressure is not proportional to the amount of fluid injected. The venous pressure does, however, become greatly increased; all the veins are much distended. More blood is returned to the heart and the cardiac output is increased. The body, however, prevents the rise in arterial blood pressure by relaxing the arterioles. There is a diminution of the difference between the arterial and venous pressures, but, notwithstanding this fact, the velocity of the circulation is increased, even to five or six times, from the injection of an amount of salt solution equal to 50 per cent. of the total volume of the blood.

The work of the heart is also increased, because, notwithstanding the arterial dilatation, there is—

1. Some rise in arterial pressure.
2. A greater frequency of heart beat.
3. An increased cardiac output.

How the Condition Is Relieved—Relief to the plethora is accomplished by—

1. The arterial dilatation.
2. A leakage of the fluid in the form of lymph from the capillaries of the intestines and liver.
3. A copious flow of urine from the glomeruli of the kidneys.

Even within two hours after the injection the total amount of fluid injected may have been eliminated.

How the Reaction from Transfusion Differs—Recovery from excessive degrees of transfusion cannot be accomplished in the same manner.

Compensation During Anemia—The opposite condition to plethora is anemia. When the total volume of blood is diminished the body maintains the arterial pressure as far as possible by three changes:

1. Increased arterial constriction.
2. Increased frequency of heart beat.
3. A transfer of fluid from the tissues into the blood through the thoracic duct.

This transfer is the direct result of the fall in the capillary blood pressure.

The transfer is extremely rapid, occurring even during the course of the bleeding; extreme thirst is a consequence of the loss of the fluid by the tissue, and if gratified will lead to the replacement of fluid to the tissues. The solid constituents of the blood are only slowly replaced.

THE PULMONARY CIRCULATION

The Total Amount of Blood Contained in the Pulmonary Circulation—All the blood in the body must pass through the lungs immediately after making the circuit of the body and before it can start again on that circuit. The lungs, therefore, must be viewed as inserted, as it were, between the vessels of the body and the heart.

The amount of blood which they contain varies much with respiration. At the height of inspiration they contain 1/12 of the whole amount of blood of the body, and at the end of the expiration between 1/15 and 1/18 of the total volume of the blood. In any case, however, there is passing through the combined sectional area of their arterial or venous circulation per unit of time the same amount of blood as is pumped out to and received from the systemic circulation.

The Special Characters of the Pulmonary Circulation—The pulmonary circulation is characterized by a number of peculiarities.

1. The blood pressure in the pulmonary artery does not exceed 15 to 20 mm. of Hg.

2. The arterioles of the lungs have very little muscular tissue and consequently very little power of contraction or control over the amount of blood passing through the lungs.

3. The capillaries of the lungs are wide.

4. Vasomotor nerves coming from the third, fourth and fifth dorsal nerves have been described, but their existence is extremely doubtful and cannot be demonstrated.

Injection of adrenalin produces no contraction of the vessels of the lung. Inasmuch as it specifically causes a contraction of all vasomotor nerve ending, its failure to give evidence of this in the pulmonary circulation indicates the absence of the muscular mechanism for vasoconstriction in the lungs.

Effect of Respiratory Changes in the Pulmonary Circulation and the Effect of the Descent of the Diaphragm upon the General Arterial Pressure—Little obstruction is offered to the passage of blood through the lungs. The arterial blood pressure is affected by respiration. It rises with each inspiration and falls with each expiration; but both these changes in pressure last over into the succeeding phase of respiration. Thus the rise on inspiration lasts into the first portion of expiration. The lungs, therefore, are capable of acting as a passive reservoir for the blood passing from them to the left heart.

The explanation of the rise of general arterial pressure upon inspiration depends upon the flow of a greater quantity of blood into the lungs as a result of the diminished intrathoracic pressure within the thorax during the enlargement of the chest by inspiration. A larger quantity of blood flows, therefore, to the heart and is pumped into the arteries, so that, as an ultimate result, the arterial blood pressure is raised.

The reverse of these conditions accounts for the fall of pressure during expiration. During inspiration another cause operates to hasten the blood to the right side of the heart and hence also to the lungs. This is the descent of the diaphragm; by the contraction of the diaphragm the intra-abdominal pressure is raised and the blood in consequence is pressed from the inferior vena cava toward the

heart; we must consider the pulmonary circulation as passing between two elastic bags. The one bag is the alveoli of the lungs; the other is the thoracic cavity. Within both of these the air pressure during expiration, but more so during inspiration, is less than the normal atmospheric pressure. The two bags tend to pull away from each other and, therefore, to enlarge the capillary space with varying degrees of force.

Still another factor in the relation of respiration to the blood pressure is the varying intrathoracic pressures upon the pericardium. The relative importance of this last factor is open to discussion. Lewis, for instance, regards the varying pressures upon the pericardium during respiration as more important than alterations in the pulmonary capacity. The differences, for instance, which he finds between the effects of deep intercostal and diaphragmatic inspiration appear to him to demonstrate that other conditions are subsidiary. For instance, a deep intercostal inspiration gives a fall of blood pressure, while a deep diaphragmatic inspiration gives a rise of pressure.

Effect of Reflex Influences from the Alveoli—During normal respiration it will be noticed that the heart tends to beat a little more slowly in the downward curve. This difference in rate between inspiration and expiration disappears after division of the vagi nerves. It is, therefore, due to a reflex action passing up to the cardiac center by the vagus nerve from the alveoli of the lungs and down again by the efferent cardiac nerves to the heart.

In contrast to the flow of blood through the pulmonary capillaries the flow through the systemic capillaries is directly controlled by the caliber of the arterioles.

THE SYSTEMIC CIRCULATION

The Appearance of the Flow of Blood through the Systemic Arterioles, Capillaries, and Veins—The flow of blood through the capillaries is best studied by observing it directly with the microscope through some thin membrane, as the web of a frog's foot.

In the small arteries the flow of blood will be rapid and pulsatile. There will be a central zone containing all the corpuscles hurrying rapidly through the vessel. Between the central zone

and the vessel wall will be a clear zone of colorless plasma about .01 of a mm. in diameter.

In the capillaries the flow of blood is inconstant, sometimes almost stopping, and again more rapid. It is always very slow and there is not a peripheral clear zone. As the blood corpuscles come to division points of the capillaries, or for that matter in the arterioles also, they can often be seen to bend or change in shape as they are forced against the dividing place in the vessels. So also as they interfere with each other in passing through the capillaries they change their shape as they are forced by obstructing places.

The varying rapidity of circulation through the capillaries depends upon changes in the caliber of the supplying arterioles. Sometimes only one, never more than two, corpuscles can pass abreast through the capillaries.

The Possibility and Causes of Variations in the Lumen of the Capillaries—The capillary wall consists of only a single layer of endothelial cells, through which diffusion can readily take place. It is a question of much importance and of great interest whether these endothelial cells are endowed with contractile power. If they are, and we believe that they are, they must greatly influence the blood pressure and variations in the distribution of the blood in the body. Changes in the caliber of the capillaries, independent of changes in the arterioles, is a very different matter from passive changes in the capillaries, which depend upon changes in the caliber of the arterioles. It is said that the cells of the capillaries are arranged in strands which pass from the nuclei around the capillary, and in the nictitating membrane of the frog they have been shown to possess a contractile power. If they do contract, they must do so in response largely to chemical stimuli. In any case, it can readily be appreciated how difficult it must be to distinguish a true contraction from a change in caliber due to alterations in the caliber of the arterioles.

Capillary Blood Pressure and Methods of Measuring It—The capillary blood pressure is measured by the weight necessary to obliterate the capillary flow through the superficial layers of the skin or mucous membrane. This pressure may also be applied through a smaller but similar bag to that used for the measurement of venous blood pressure. The obliteration is accomplished when

blanching of the surface has been produced. There are many inaccuracies in this method, and obviously the capillary blood pressure is so closely dependent upon the relation between the pressures in the arterioles and venules that measurements of the variations in the pressures in these afferent and efferent vessels will form a very accurate means of estimating the capillary blood pressure, although it stands in a closer relationship to the pressure in the venules than in the arterioles.

If both a rise and fall of the arterial and venous pressure, the capillary pressure must rise or fall with them. When one rises and the other falls it may be difficult to say what happens to the capillary pressure.

Factors Originating in the Capillaries Themselves Which Influence the Capillary Blood Pressure—The resistance to the flow of blood through the capillaries depends upon the internal friction of the capillary walls and the viscosity of the blood. These factors will cause a diminution of the capillary blood pressure as it flows from one end of the capillaries to the other end.

It has been estimated that the diminution of the capillary blood pressure at the end of a capillary from that at its beginning never amounts to more than 150 mm. of blood or 10 mm. of Hg. It usually is one-eighth to one-half of this amount.

The Different Capillary Pressures—In the horizontal position the capillary blood pressure is about 10 mm. of Hg. It is influenced by hydrostatic pressure. At the end of the finger it varies as follows with the distance of the finger below the head:

0 mm. below the head equals 328 mm. of water.
205 mm. below the head equals 329 mm. of water.
490 mm. below the head equals 513 mm. of water.
840 mm. below the head equals 738 mm. of water.

The Factors Influencing the Return of Blood through the Veins—The mechanism of the flow of blood through the veins is quite as important as that through any other portion of the vascular system. Upon the quantity of blood passing back to the heart through the veins depends absolutely the maintenance of any circulation at all. The blood meets with only a negligible resistance aside from hydrostatic pressure in its passage through the veins back to the heart. Its passage back to the heart will depend solely

upon a progressive diminution of pressure in the direction from the periphery of the body toward the heart.

The pressure in the great veins near the heart is below 0 most of the time. During each inspiration this minus pressure is increasing, so that during inspiration blood is sucked toward the heart. During diastole the heart yields to the negative pressure in the chest and takes regularly a definite quantity of blood from the great veins. This amount must in turn be made up by the flowing of more blood into the great veins from the periphery.

This explanation meets perhaps all the factors of the problem when the body is in a horizontal position. What, however, explains the return of blood from the lower limbs in the upright position of the body? We would naturally expect that this position would greatly increase the pressure of the blood in the venules of the foot by an amount equal to the difference between level of the foot and the heart.

As a matter of fact it does not. It is true that the blood pressure in the veins of the foot in the upright position of the body is higher than that of the veins of the hand when the latter occupied the level of the heart.

Indeed, if we should subtract the hydrostatic pressure measured in terms of blood and representing the distance between the level of the foot and heart from the actual pressure in the veins of the foot, we would have a minus pressure of 40 cm. of blood. Hill has stated that there is very little difference between the blood pressure in the capillaries of the hand and those of the foot, and has shown that when a man assumes the upright position the arteries of the leg contract, thus holding back the blood from the leg and so completely controlling the amount of blood entering the capillaries that the intracapillary blood pressure is not raised proportionally to the degree with which the foot is depressed below the heart when the upright position is assumed.

Of course, any increase of hydrostatic pressure in the venules will be equaled by an increase of hydrostatic pressure on the arterial side, so that in the presence of unyielding walls in the veins and arterioles the progressive difference in pressure between the aorta and vena cava, due to the propulsive force of the heart, will still be effective in returning the blood through the veins.

The unyielding walls upon the arterial side of the circulation

are furnished by the contracting arterioles, and upon the venous side of the circulation support is furnished to the veins by the normal tone of the skeletal muscles and the increased pressure which they exert during voluntary contraction and the pressure of fascial planes.

Variations of the capillary blood pressure as the hand occupies different levels indicate that equalization by hydrostatic pressure on the two sides of the capillaries plays a part in the return of the venous blood to the heart. The low blood pressures found in the

FIG. 44.—VENOUS PULSE-TRACING FROM JUGULAR VEIN COMPARED WITH THE ARTERIAL PULSE-TRACING FROM THE RADIAL ARTERY. (Starling.)

venules of the foot, however, indicates that the most important factor in the return of venous blood certainly in the lower extremity is the contraction of the vouuntary muscles and the support of fascial planes. These contractions compress the veins and so force the blood on toward the heart. Their efficiency is maintained by the presence of little valves in the veins which prevent any flow backwards toward the capillaries. Each segment of a vein between two of these valves compressed by the muscles external to the vein may be considered as an additional heart propelling the blood on to the main pump of the body.

Venous Pulse Tracings—Tracings taken from the jugular veins show definite changes of pressure within the veins which correspond to changes in the intra-auricular pressures. There are three definite pulsations of the veins with each cardiac cycle, and each of these produces a wave in the tracing. (Fig. 44.)

There is a large wave due to contraction of the auricle followed almost immediately before the fall of the first wave is complete by a wave of equal height due to the increase in auricular pressure

caused by the contraction of the ventricle. The curve then falls to the base line and rises again a short distance to produce the third wave as the auricle fills with blood.

THE PHYSIOLOGY OF THE HEART

The Great Functional Characteristic of Heart Muscle—Functionally the heart muscle presents differences from other muscle tissue which, even though they may be explained entirely as differences in the degree with which muscle manifests its activity, are nevertheless so striking that they indicate a special differentiation in function. The first striking characteristic of heart muscle is its automaticity. An excised heart of a cold-blooded animal, as a frog or tortoise, will continue to beat with a normal sequence of the various chambers for hours or days, provided it is kept cool and moist. The heart of a warm-blooded animal will also continue its activity under proper conditions for surprisingly long periods. Thus the heart contains within itself a complete mechanism for its own activity, and, cut off from all connections with the central nervous system, it is able to maintain its own rhythmic contractions.

The Nervous Tissue of the Heart—Though cut off from all nervous connections, the heart is not devoid of nervous tissue. A collection of ganglia cells, the ganglion of Remak, exists in the sinus venosus. Another collection exists near the auriculo-ventricular grove (Bidder's ganglion). From these collections of nerve cells fine non-medullated fibers pass to all parts of the heart wall.

The Possible Relation of the Nervous Tissue of the Heart to Its Automaticity—It is very natural to assume that the cause for the automaticity of the heart's action resides in these ganglia, in other words, that the heart is capable of a spontaneous rhythmic pulsation because of impulses which are started by the nerve cells in these ganglia. A number of facts lend color to this view.

The Effects upon the Heart's Automaticity of Applying the Stannius Ligature Progressively Nearer the Apex of the Heart—If the sinus of the frog's heart is separated from the rest of the heart by cutting the heart across between the sinus and the auricle or by applying a ligature around the sino-auricular juncture (Stan-

nius ligature), the sinus will go on beating with its own rhythm, but the ventricle and auricle will stop beating altogether for a time. After the lapse of five minutes to half an hour the auricles and ventricles will begin again to beat, at first slowly and a little later more rapidly, but never as rapidly as the rhythm of the sinus. If now instead of dividing the heart at the sino-auricular juncture the section is placed at the auriculo-ventricular juncture, the sinus and auricles will go on beating with their normal rhythm, but the isolated ventricles will only begin to beat again slowly and after the lapse of a much longer time than is the case with the auriculo-ventricular preparation. If a third preparation is made consisting only of an apex of the heart, the isolated portion will not beat again at all. It may respond by a single contraction to one induction or galvanic shock, but it cannot spontaneously start beating again or be stimulated by ordinary means to maintain continued rhythmic contraction.

We see, therefore, that there is a progressive diminution of the power to originate and maintain rhythmic contractions in the isolated lower third of the frog's or tortoise's ventricle. Supplied with salt solution by perfusion under pressure or by the passage of a constant current or continued weak induction shocks, it will begin to rhythmically contract.

The above facts in reality lend no support to the theory of the nervous or ganglionic origin of the automatic rhythmic activity of the heart, they do not contradict the myogenetic theory of the origin of the cardiac contractions, while the following facts demonstrate that the heart muscle itself is alone responsible for the automaticity of its activity.

By crushing above the apex of the heart the latter can be separated from the rest of the heart by a cone of crushed and functionless tissue, but the apex will still remain attached to the heart, so that the heart will not leak. Only the portion of this heart above the crushed zone will contract automatically. If, however, the intraventricular pressure is raised by clamping the aorta, the apex will once more contract rhythmically.

It is possible to cut out a strip of muscle free from any ganglion cells from the apex of the tortoise heart; such a strip will enter into rhythmic contractions under the stimulus of salt solution in a moist chamber.

In the frog's heart and still more easily in the tortoise heart it is possible to excise nearly all the ganglia and nerve fibers of the heart without interfering with the rhythmic contractions of the heart. (Fig. 45.)

The chick's heart beats before ganglion cells and nerve fibers have been developed within it.

Remak's ganglia are developed in connection with the vagus nerve and where this nerve enters the heart. The cells of the

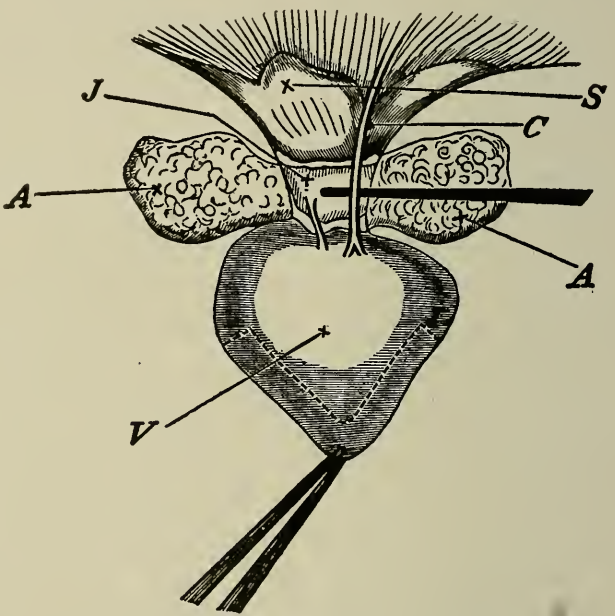


Fig. 45.—Ventricle of the Tortoise Heart Turned Over, to Show the Connection of the Sinus (S) by Means of the Junction Wall (J) with the Ventricle (V) and the Auricles (A). The Point of the Seeker Is Placed Under the Free Coronary Vein and Nerve (C).

The dotted line shows how a strip may be cut from the ventricle without containing nerve tissue. (W. H. Gaskell.)

ganglion mark the transition between the post and preganglionic fibers of this nerve. Nicotin possesses a selective paralyzing action on ganglionic cells. After its application to the ganglia stimulation of only the postganglionic fibers of the vagus nerve will produce slowing of the heart, a fact which demonstrates that after the painting with nicotin the ganglionic cells are functionless.

Under these conditions, that is, after the application of nicotin, the automatic rhythm of the heart is in no way interfered with. The ganglia must, therefore, be regarded as distributing centers for the vagus nerve.

A weak tetanizing current causes local inhibition of the heart's action. Inasmuch as the application of atropin abolishes this effect, these weak currents must act on the finer postganglionic fibers throughout the heart.

The function of these fibers must, therefore, be inhibitory in their nature and not connected with the maintenance of the automatic rhythmic contractions of the heart.

The True Character of the Functional Relation between the Auricles and Ventricles—Normally each cardiac cycle starts at the

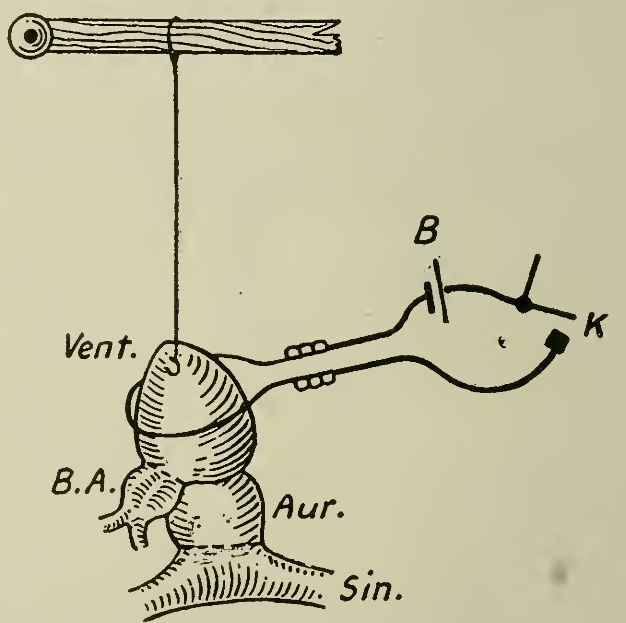


Fig. 46.—Arrangement of Platinum Loop Through Which a Current Capable of Warming the Loop May Be Sent and by Which the Heart May Be Stimulated at Different Levels Between the Apex and Auricles.

sinus venosus and proceeds from this structure over the whole heart. The normal sequence is sinus venosus, auricles, ventricles and bulbus arteriosus. After separating these portions of the heart by section or crushing, the rhythm characteristic of each separate portion can be recorded. From the sinus down there is a decreasing rapidity of rhythm. The normal rhythm of the ventricle, that is, that which in the intact heart corresponds with the rhythm of the sinus, depends upon the propagation of an excitation from the sinus to the ventricles.

The ventricle cannot, in other words, beat with its own rhythm

because it receives from the sinus a stimulus at each beat of the latter which is responsible for its faster rate in the intact heart. The importance of the transmission of impulses through the heart is further emphasized by the fact that it is possible to create a reversed rhythm from ventricle to auricle by stimulating the former at a faster rate than that of the sinus venosus.

The differences in automaticity between the sinus and ventricle are further illustrated by the effect of warming each by a conducting platinum loop. (Fig. 46.) Warming the ventricle will call forth a strong beat without altering the rhythm. Warming the sinus will quicken the rhythm without increasing the force of the beat. The ventricular cell is a more highly differentiated one than the cell of the sinus venosus. In consequence it is more dependent for the manifestation of its activity upon stimulation and its response is a more powerful one. "It is a good servant of the sinus."

The Tissue Transmitting Impulses from the Auricle to Ventricle—What is the tissue which propagates the impulse from the sinus to the ventricle? We have already discussed the impossibility of its being the nerves in the heart.

Moreover, the mere possibility of exciting a reversed rhythm of contractions in a heart is evidence against the view that the nerves of the heart propagate the stimulus resulting in coordinated rhythmic contractions of the whole heart. They could not be the transmitting agent without furnishing an exception to the law of forward direction. The auricle may be slit up by a series of interdigitating cuts in a manner to divide the normal course of any nerve tracts. Still the impulse to contraction will pass around all the cuts from the sinus venosus and finally reach the ventricle, which it stimulates. When the bridges of muscular connections are made exceedingly narrow the wave of contraction halts in a definite pause in its passage over such an auricular bridge. (Fig. 47.)

By soaking the auricles for some time in distilled water they will become incapable of contracting, but still capable of transmitting an impulse. The most obvious explanation of all these experiments is that the muscular tissue of the heart not only originates its own rhythm but serves as the agent by which a uniform rhythm or impulse to contraction is transmitted over the whole heart.

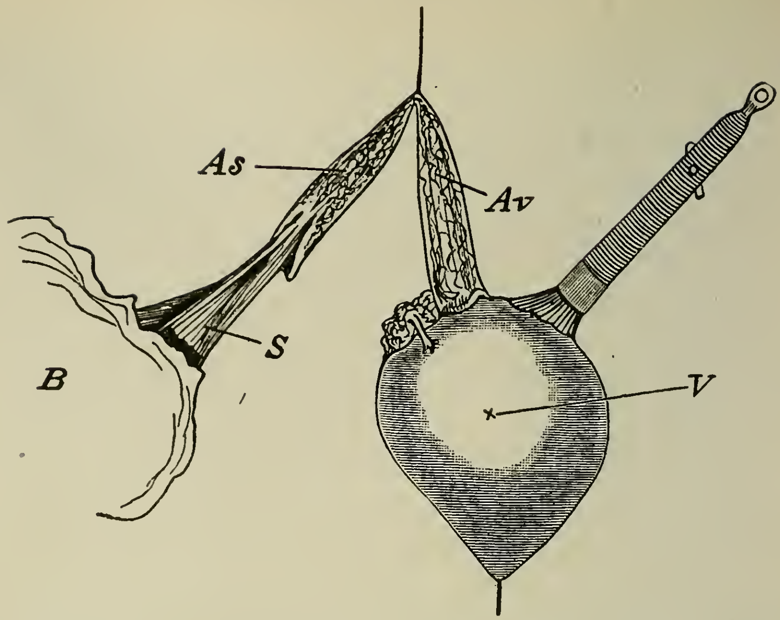


Fig. 47.—Heart of a Tortoise with Auricle Slit Up so as to Separate Auricle into Two Parts, As, Av.

Connected by only a small strand of muscular tissue. (W. H. Gaskell.)

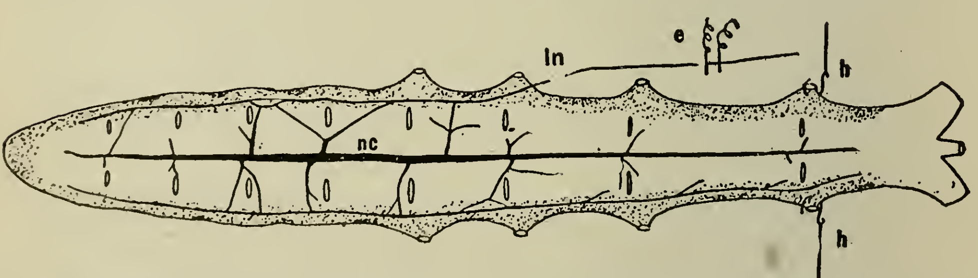


Fig. 48.—Preparation of the Heart of King Crab for the Study of the Local Cardioreflex Dorsal View.

nc, Nerve cord; *ln,* lateral nerves; *h,* hooks for connecting a region of the heart with the lever; *e,* electrodes. The nerve, *in,* may be dissected out for half of its length and used to convey a stimulus to the portion of the heart to which it is still connected.

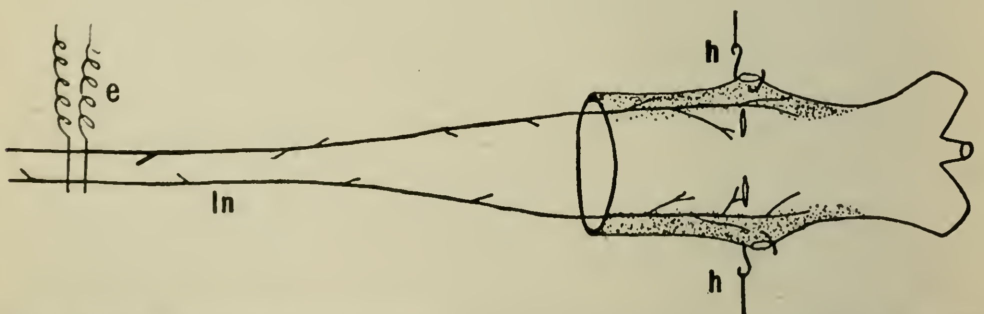


Fig. 49.—The True Muscle Nerve Preparation Which May Be Made from the Heart of the King Crab.

In one of the lower animals, notably the king crab, there seems to be a possible exception to this view, and a large share in the transmitting mechanism is taken by the nerves. In fact, it is possible in the king crab to make a true muscle-nerve preparation of the heart and to stop all transmission by excision of parts of the gangliated cord. This animal, however, must form a special case. (Fig. 48 and 49.)

Time of the Contraction of Heart Muscle—Heart muscle possesses its own time of contraction, while voluntary muscle con-

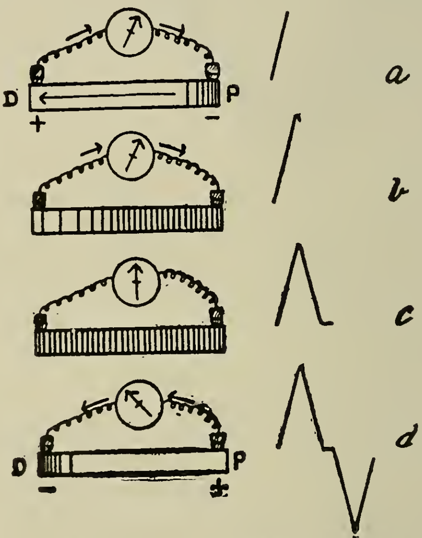


Fig. 50.—Diagram Illustrating the Development and Subsidence of Activity (and Negativity) in a Single Muscle Strip. Responding to a Stimulus Applied at P.

The corresponding and successive phases of the galvanometric curve are shown in the four lines *a, b, c* and *d*. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

tracts in about one-tenth of a second. The contraction of the tortoise heart lasts 2 seconds. The contraction of the mammal's heart lasts from .3 to .4 of a second.

The Electrical Changes Which Accompany Cardiac Contraction, the Information Which They Supply upon the Development of the Shape of the Mammalian Heart and the Propagation of the Impulse Controlling Contraction Through the Heart—*The Portions of the Primitive Heart Which Are Represented by the Various Portions of the Mammalian Heart*—A wave of contraction passing over an excised strip of heart muscle is accompanied by a typical diphasic electrical change. Any spot passed by the wave becomes

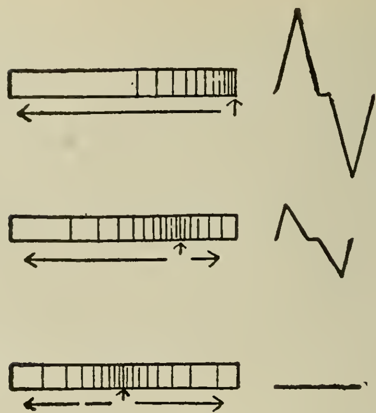


Fig. 51.—Diagram to Show That Maximal Excursion of the Galvanometric Recorder Is Obtained When the Interval of Delay Between the Arrival of the Excitation Wave at the Contact Is Greatest. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

at first negative to all other portions of the muscle and actively positive again as the wave passes beyond the spot. (Figs. 50, 51 and 52.)

The electrical change accompanying the wave of contraction which passes over the intact heart is somewhat more complicated. This is due to the fact that the heart of the frog or mammal has undergone a change from the simple tubular heart of the fish.

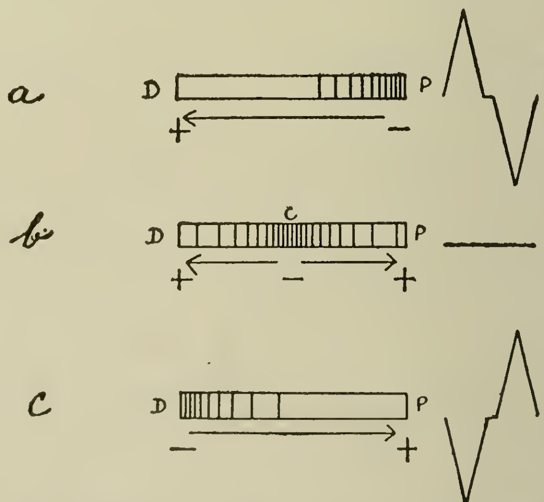


Fig. 52.—Diagram Illustrating the Inversion of the Curve When the Order of Contraction Is Reversed, and Its Isopotentiality When the Ends of the Strip Are Activated Simultaneously.

The directions in which contraction is driven are indicated by the arrows. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

In virtue of this change the bulbus arteriosus has rotated from one end of the simple tubular heart to a position at the base of the heart.

There passes, therefore, over the base of the heart of the frog or mammal two diphasic changes. The base is first negative, then positive, as the apex becomes negative, and finally the base becomes negative as the bulbus arteriosus becomes in its turn excited. (Fig. 53.)

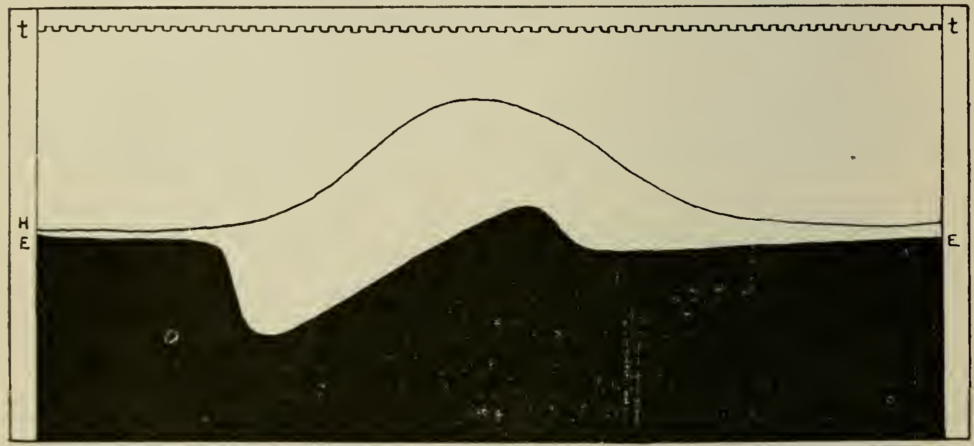


FIG. 53.—A CARDIOGRAM ILLUSTRATING A SINGLE DIPHASIC CHANGE DUE TO A SPONTANEOUS CONTRACTION OF A PORTION OF A FROG'S HEART MUSCLE.

H is the diphasic electrical change in the heart muscle; E is the simultaneously recorded mechanical change.

Like the frog's heart, the mammal's heart contains ganglion cells around the openings of the great veins, along the borders of the interauricular septum and in the auriculo-ventricular groove.

The Difference in Automatic Power of Contraction Possessed by the Mammalian Heart as Contrasted with That of the Amphibian Heart—The ventricle of the mammal possesses a greater power of automatic rhythmic activity than the ventricle of the frog or tortoise heart. The whole heart of the mammal may be kept beating for hours if it is perfused through its coronary arteries by Ringer's solution or by defibrinated blood. The ventricle of the mammal's heart which has been separated from the auricles, except for fibrous connections, by crushing all nervous and muscular tissue in a plane between the auricle and ventricle, will not stop even for a moment its rhythmic contraction. These

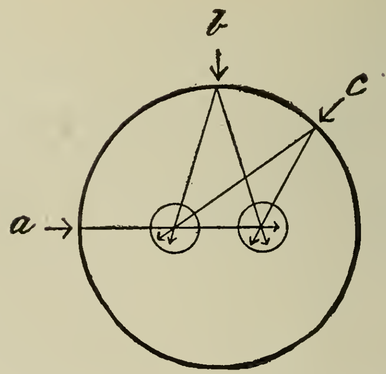


Fig. 54.—Diagram Illustrating Stimulation of a Sheet of Muscle.

The circle represents a sheet of muscle, excited at *a*, *b* or *c*, and examined at two central contact points. The excursion of the recorder is greatest when the contacts are in the line with the point of excitation; i.e., when the muscle is stimulated at *a*. It is least when stimulation is at *b*, for in this circumstance activity is simultaneously developed at the contacts. (From Lewis, ''Lectures on the Heart,'' Hoeber, New York.)

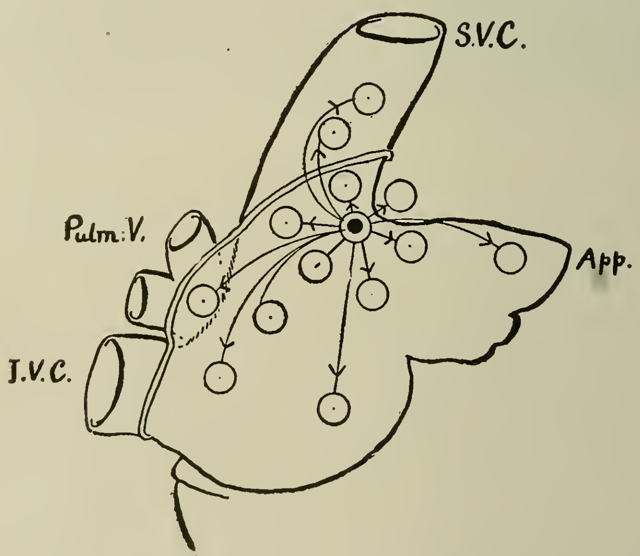


Fig. 55.—The Contacts as Applied to an Auricle.

When the central contact overlies the sino-auricular node, it is invariably relatively negative to outlying points and the height of the curve, which is always proportional to the distance which this state of negativity must travel in order to reach the second contact, can be used to map out the direction taken by the spread of this wave of negativity or the mechanical change which it accompanies over the heart. (From Lewis, ''Lectures on the Heart,'' Hoeber, New York.)

independent contractions of the isolated mammal's ventricles are, however, slower than those of the intact heart.

The Character of the Electrocardiogram Waves in the Human Heart—It is possible to use the electrical variations of the differences in potential between the base and apex of the mammal's

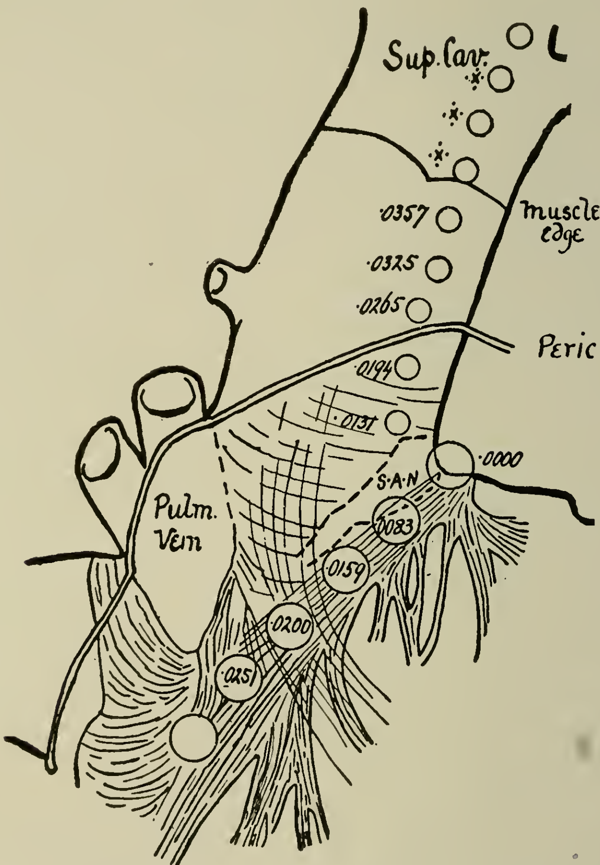


Fig. 56.—Serial Leads Over the Auricle from the Sulcus and Superior Cava.

The times at which the excitation wave appeared at the several contact points are given and make possible the mapping out of the course taken by the excitatory wave. From the highest S.V.C. (contacts marked *) no intrinsic deflections were obtained. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

heart as an index of the course and time relations of the excitatory wave which passes over a heart. (Figs. 54 to 61.) These may be recorded by leading off a point over the apex of the heart and another point over the right shoulder or right arm in the intact body. (Figs. 62 and 63.)

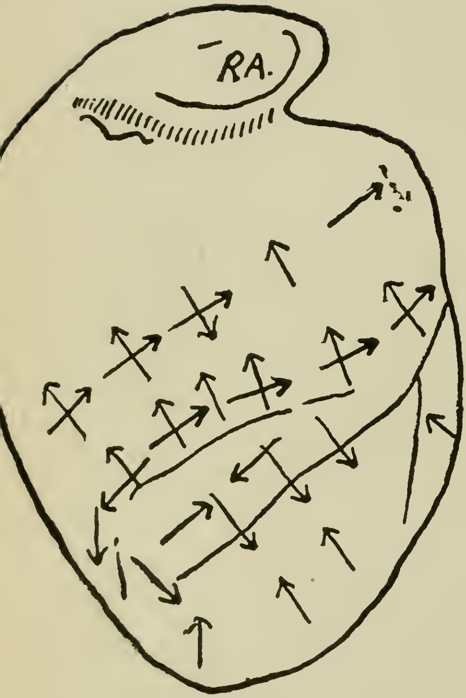


Fig. 57

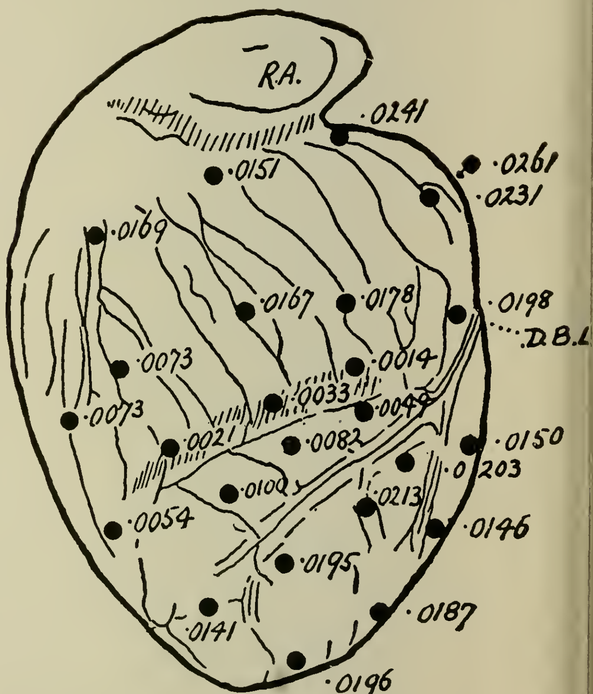


Fig. 58

FIGS. 57 AND 58.—ILLUSTRATING MANNER IN WHICH THE COURSE OF THE EXCITATORY WAVE MAY BE MAPPED OUT FOR THE WHOLE HEART.

Outlines of the front of the heart in an actual experiment.

Upon Fig. 57 arrows have been drawn; they depict the direction of spread on the front of this heart, investigated by means of closely paired contacts. Here the direction of the deflection was the index.

FIG. 58.—The times at which the excitation wave appeared on the front of the same heart, related to the upstroke of R in the lead II.

R.A., Rt. appendix.

R.B.L., Descending branch of left coronary artery. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

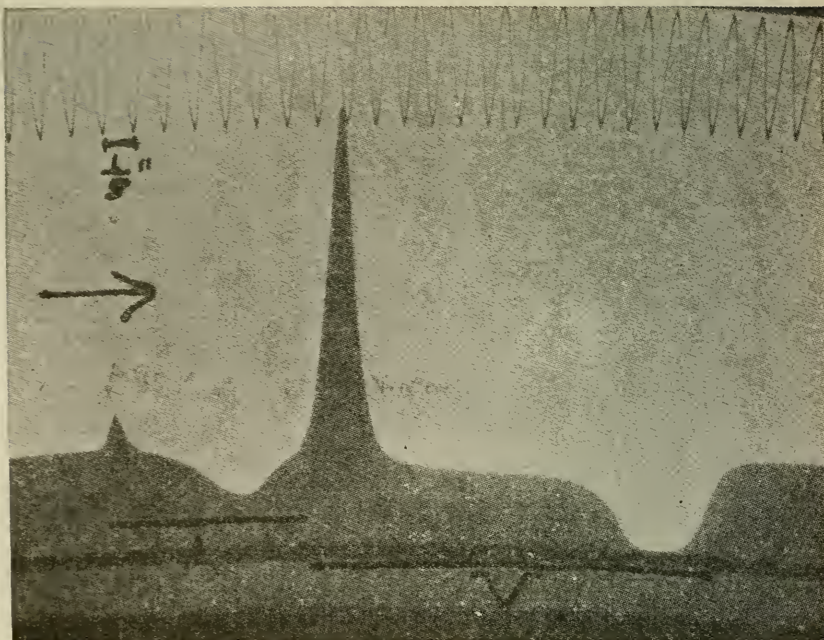


FIG. 59.—ELECTROMETER RECORD WITH THE CONTACTS UPON THE SINUS AND THE VENTRICLE APEX RESPECTIVELY.

Upward movement signifies relative negativity of the sinus contact (tortoise heart). One beat only is shown in the record. (Gotch.)

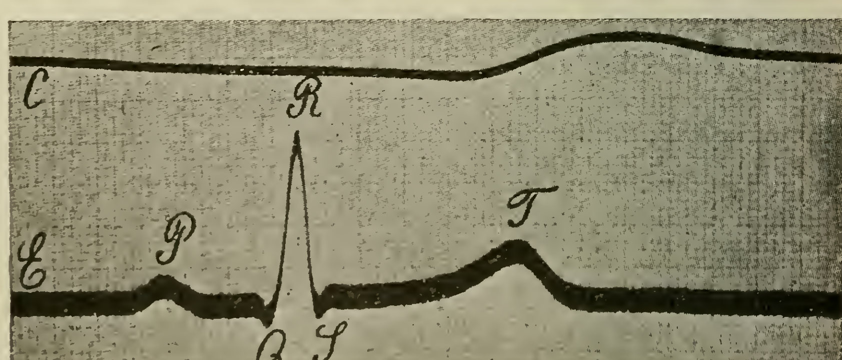


FIG. 60.—ELECTROCARDIOGRAM OF MAN, OBTAINED BY LEADING OFF FROM THE TWO HANDS TO A STRONG GALVANOMETER, TAKEN SIMULTANEOUSLY WITH A CAROTID PULSE TRACING.

C is the carotid pulse tracing. The different parts of the curve are designated by the letters P, Q, R, S, T, first applied to them by Einthoven. (Starling.)

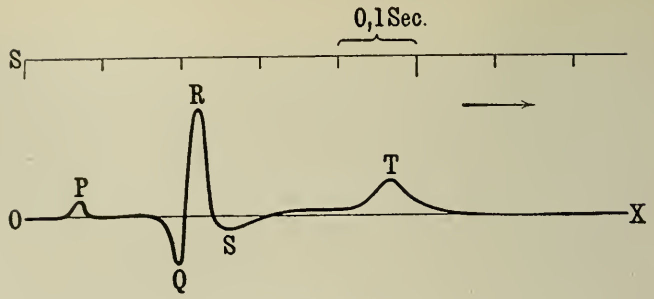


FIG. 61.—SCHEME OF ELECTROCARDIOGRAM.

The P wave represents contraction of the auricle; Q to T represents the total period of ventricular contraction.

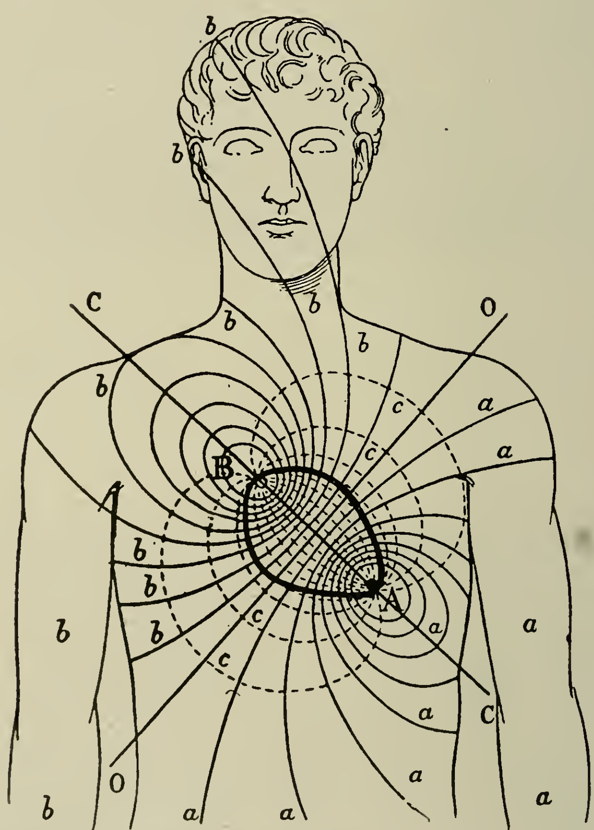


FIG. 62.—CHARACTER OF ELECTROCARDIOGRAM WAVES IN HUMAN HEART.

Let A and B respectively represent apex and base of the ventricular mass. Then, if at any moment a difference of potential should arise between A and B a current, *c c c*, will be established along and around the axis C C; the line O O will represent the plane of zero potential or equator; the lines ***a a a***, ***b b b*** will represent equipotential curves around A and B. A difference of potential between A and B will be manifested if two leading-off electrodes are applied on opposite sides of the equator, O O; no such difference will be manifested if both electrodes are on the same side of the equator. The equator O O will divide the body into two asymmetrical parts, (1) a portion ***b b b*** including the head and right upper extremity, (2) a portion ***a a a*** including the three other extremities. (Waller.)

The waves of such electrical changes recorded on a moving sensitive surface present three typical diphasic variations precisely as if the leading off points were taken from the heart itself.

In fact, the two terminals of the galvanometer circuit may be held in the hands of the patient whose heart's action is being recorded. A typical electrocardiogram shows three waves, each consisting of a rapid rise and fall, in other words, of diphasic variations. The first wave is a small one and is certainly due to the auricular contraction. The high elevation the contraction of the ventricle at the base. The fall of this high wave is due to the

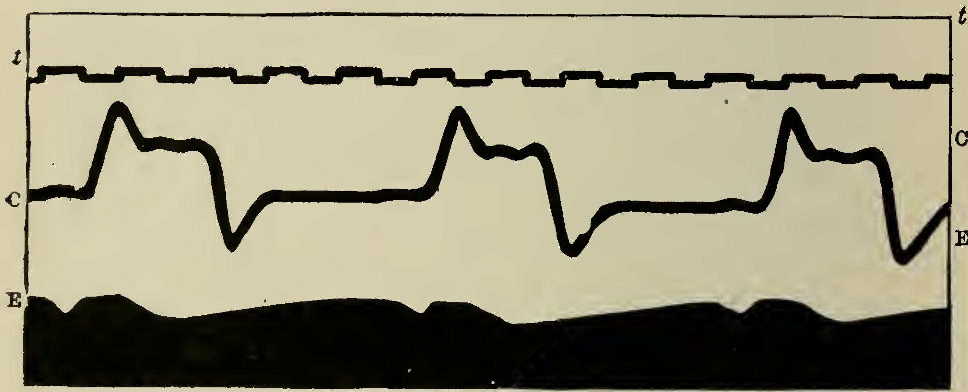


Fig. 63.—Character of Electrocardiogram Waves in Heart.

Diphasic variation, E E; land simultaneous cardiogram, C C.
The leads-off to the capillary electrometer were from the mouth to the sulphuric acid, and from the left foot to the mercury. Time, *t t*, marked in one-tenth second. (Waller.)

passage over the rest of the ventricle of the wave of contraction as the apex becomes negative. The third elevation is a small one and due to the contraction of the bulbus arteriosus in the region of the base. It becomes first negative and then positive as the wave of contraction passes over it.

Embryological Units of the Human Heart—The portions of the heart showing these separate electrical variations represent the separate components of the primitive heart, namely, the sinus venosus, auricle, the ventricle and the bulbus arteriosus.

The excitation of the reverse of the sequence of events in the mammal's heart, i.e., a contraction first of the ventricle and last of the auricles, is possible in the human heart by stimulating the ventricle at a rate slightly faster than the normal rhythm of the

auricles. It indicates that the propagation of the impulse over the mammal's heart is not accomplished by the nerves in the heart.

The Bundle of His and Its Transmitting Function—Except for the bundle of His, first described by Kent, there is no continuity of muscular structure between the auricles and the ventricles. This bundle in the human heart begins in the cardiac tissue in close connection with juncture of the superior vena cava and the

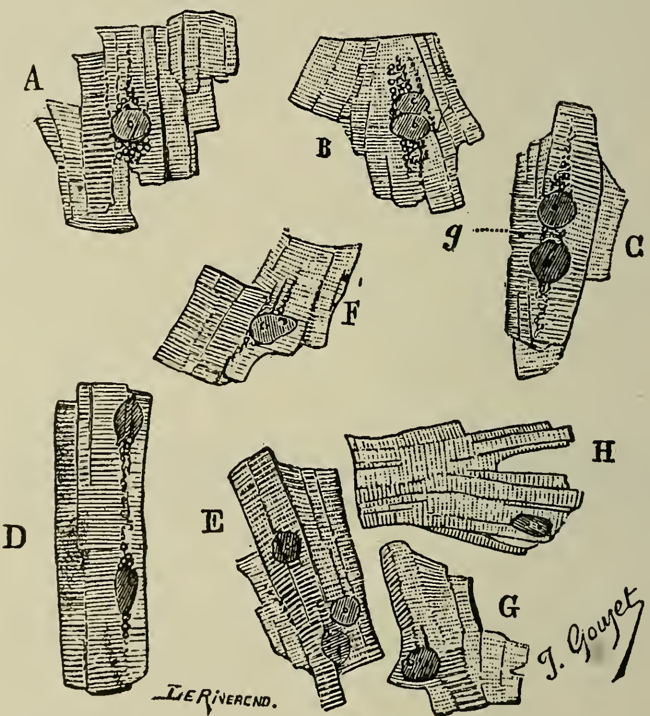


Fig. 64.—Ordinary Muscular Cells of the Human Myocardium, Showing the Branching.

The cells have been isolated by teasing a piece of muscle in ammonia picrocarminate.

A, B, C, D, E, F, G, H, muscular cells of the heart of various forms; *g*, granules or striations. (Renaut.)

right auricle (the so-called sino-auricular node). The sino-auricular node consists of muscular tissue of a still more primitive character than the fibers of the bundle of His. It lies in the wall of the sinus venosus between the auricular appendix and the superior vena cava but close to the latter in the groove between it and the right auricle and the superior vena cava. Another node, the auriculo-ventricular node, to be regarded probably as the extension of the

sino-auricular node, lies at the base of the auricular septum on the right side, below and to the right of the opening of the coronary sinus. It is to be regarded as the first portion of the bundle of His

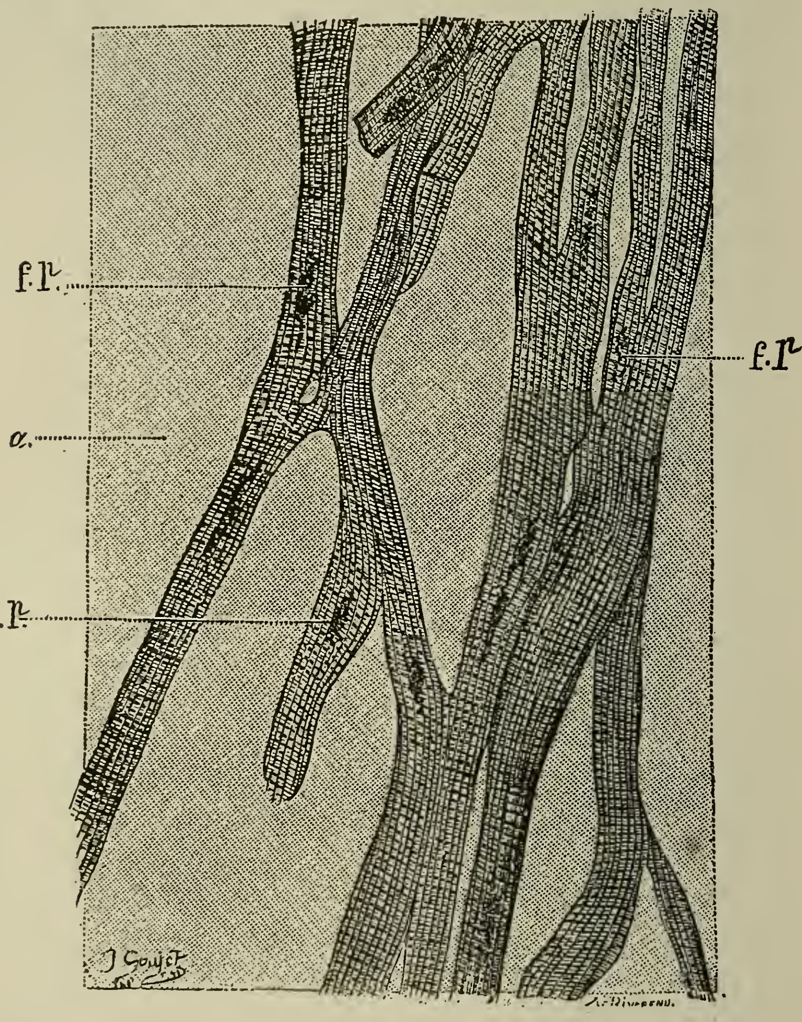


FIG. 65.—ORDINARY MUSCULAR BUNDLES FROM THE HUMAN HEART, FORMING A NETWORK BENEATH THE ENDOCARDIUM, FIXED IN OSMIC ACID.

fp, Protoplasm bulged out by the nucleus of each cell. (J. Renaut.)

which may be said to be intimately associated with the sino-auricular node from which it begins.

Passing along the top of the interventricular septum, the bundle divides into two parts for each ventricle. These two portions pass in the surface of each side of the interventricular septum and into the papillary muscles of each side. From the papillary muscles fiber bands radiate to the apex.

The muscular fibers constituting the auriculo-ventricular bundle are of a more primitive character than the rest of the heart muscle and contain a high content of glycogen. (Figs. 64 to 67.) Accurate electrograms of the heart muscle demonstrate that the heart beat begins in the sino-auricular node. It is the "pacemaker" of the heart.

Conduction along the auriculo-ventricular bundle is ten times

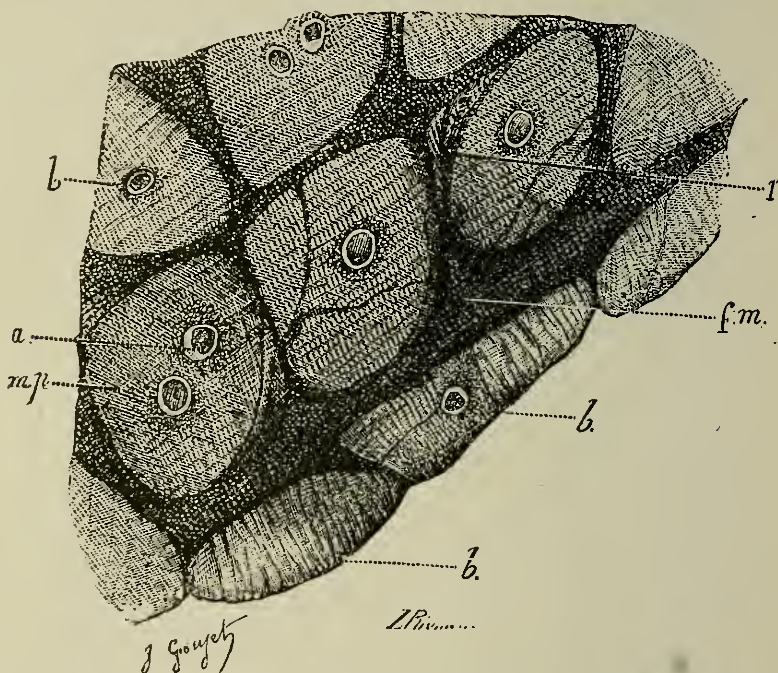


FIG. 66.—SECTION OF THE PURKINJE CELLS. SILVER PREPARATION.

a, Nuclei; *mp*, protoplasm of the cells containing granules; *fm*, muscular fibers; *r*, network formed by the muscular fibers at the surface of the Purkinje cells; *b*, deep striation parallel to the axis of the cell.

as fast as conduction through the ordinary tissue of the heart. (Fig. 68.) In virtue of this fact it is easy to trace their course. They are called the fibers of Purkinje. Disease in this bundle, a degeneration called Adams-Stokes disease, is accompanied with failure of the normal transmission of the rhythm of the cardiac beat from auricle to ventricle. There are more auricular contractions than ventricular contractions, a fact confirming the view stated regarding the function of this bundle.

The Maximum Character of the Shortening of Cardiac Contractions—Heart muscle, as every muscle, requires a stimulus of

a certain strength to evoke a single contraction. The resulting contraction is, however, always a maximum contraction. There is either evoked a maximum contraction or none at all. The same fact is true for each individual fiber of voluntary muscle, but in-

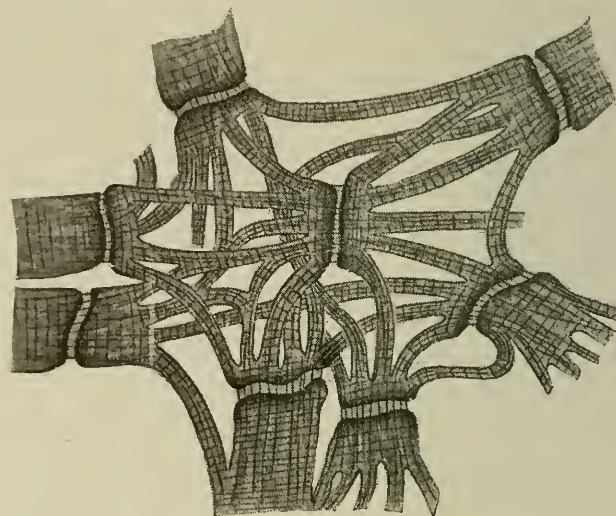


Fig. 67.—A Preparation of the Purkinje Fibers of the Bundle of His.

asmuch as certain weaker stimuli, when applied to voluntary muscles, will not stimulate all fibers, it is possible to evoke contractions of graded strength in voluntary muscle. The branched and anastomosing character of heart muscle makes possible the transmission of an impulse started in one muscle fiber to the other fibers, so that the heart as a whole will give a maximum contraction or none at all as the result of stimulation.

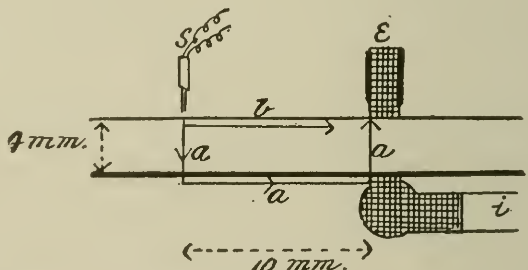


Fig. 68.—Two contacts ($e =$ external, $i =$ internal) are placed on the epicardium and endocardium respectively, and the heart wall is stimulated at S, 10 mm. away. The excitation appears at a natural interval before it appears at the external contact; it travels therefore more quickly by way of the Purkinje substance. (From Lewis, "Lectures on the Heart," Hoeber, New York.)

Apparent Summation Only Due to Blocking and Therefore to Incomplete Primary Stimulation—An apparent summation of effect from two stimuli may be obtained if in any way the transmission of the first stimulus is interfered with by block, as, for instance, an inhibitory action of the vagus nerve or by drying of the heart muscle. In this case the stronger contraction evoked by the second stimulus is due to the successful transmission of the second stimulus, but not the first. In a Stannius preparation the heart will respond to single induction shocks of not too great a strength, applied every ten seconds, by an increasing height of contraction during the first four or five stimuli.

Possible Slight Effect from Subminimal Stimuli—Some evidence also exists that even subminimal stimuli are not without effect on the heart muscle. The repetition of several subminimal stimuli applied at short intervals of time may give rise to a contraction. This is to be interpreted as further evidence that there is no essential difference in the nature of the contractions of heart muscle and voluntary muscle.

The Refractory Period of Heart Muscle—The period immediately following the normal excitation of heart muscle which leads to its contraction, i.e., the period between two cardiac contractions, has been called the refractory period, because during this period it will not respond to stimuli of ordinary strength, we may say to minimal stimuli. We can conceive that each cardiac cycle is set into operation by the explosion, so to speak, of combustible material collecting during the refractory period.

At the beginning of this period the irritability of the heart is at its minimum, while at the end of this period it may be considered to be at its maximum capable of exploding upon the application of a minimal stimulus.

If, therefore, immediately after the refractory period has ended an extra contraction is evoked from a ventricle by the direct application of a very strong induction shock, the pause following this contraction will last over the time of the next stimulus which arrives from the sinus venosus until the normal time of the second ventricular contraction after the application of the strong induction shock, inasmuch as the next impulse from the sinus venosus after the extra-ventricular contraction arrives early in the refrac-

tory period of the ventricle following the extra contraction which has been evoked. (Fig. 69.)

Often the ventricular contraction, following the long pause and

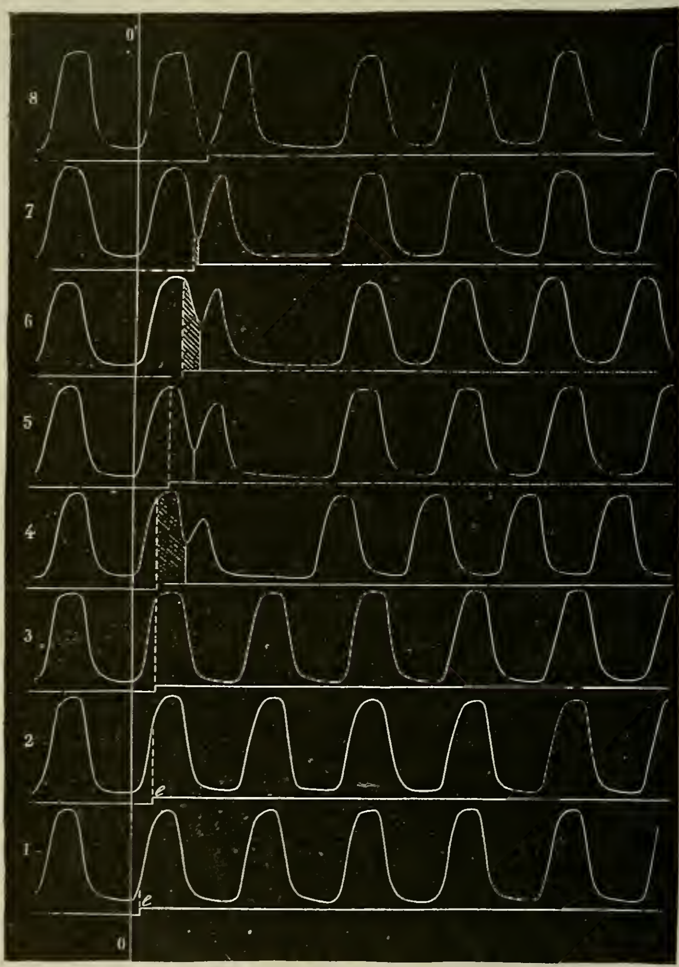


FIG. 69.—TRACING OF SPONTANEOUS CONTRACTION OF FROG'S VENTRICLE TO SHOW REFRACTORY PERIOD.

In each series the surface of the ventricle was stimulated by an induction shock at E, as indicated by the base line of each series. In 1, 2 and 3 this stimulus had no effect since it fell during the refractory period. In 4, 5, 6, 7, the effect of the shock was to interpolate an extra contraction in the series, the latent period (shaded portion) gradually diminishing from 4 to 7 (diastolic rise of irritability). In 8 the irritability was already considerable and the latent period inappreciable.

The compensatory pause after the extra beat is also well shown in 4, 5, 6, 7, 8. (Marey.)

resulting from the second impulse from the sinus venosus, is greater. On account of the refractory period it is impossible to tetanize heart muscle. By using very strong stimuli, as has been indicated,

extra contractions may be intercalated, so that contractions may follow each other rapidly and produce a notched elevated curve somewhat resembling the curve of a tetanus, but differing from

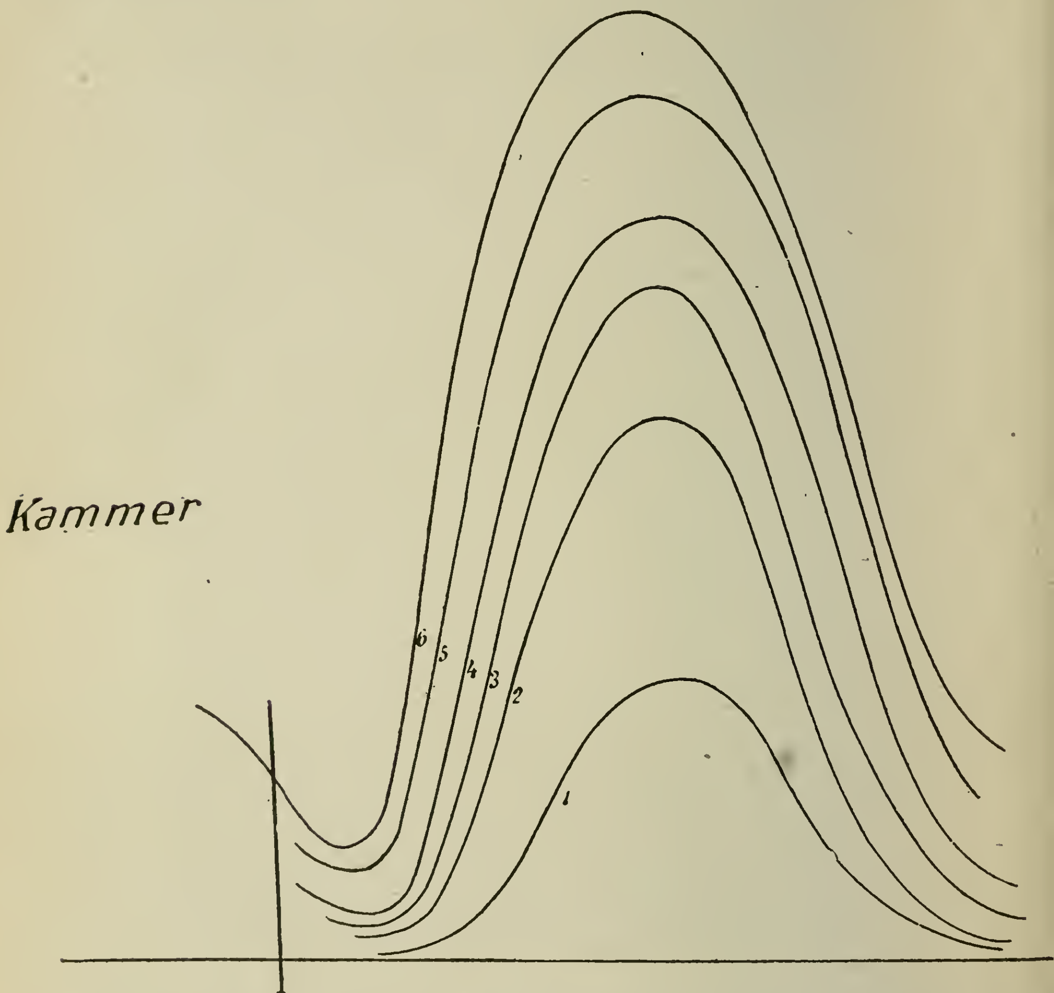


FIG. 70.—CURVES ILLUSTRATING THE PROGRESSIVELY GREATER ISOMETRIC CONTRACTIONS OF HEART MUSCLE DEVELOPED BY INCREASING THE DEGREE OF FILLING OF THE VENTRICLE DURING DIASTOLE.

It must be remembered that no isometric contraction of muscle is absolutely isometric, but only nearly so, and may therefore be measured by greatly magnifying by the recording device the small change in the length of the muscle. (Otto Frank, *Zeitsch. biologie*, 14.)

a true tetanus in that the summits of the curves representing the extent of the contractions are no higher than single contractions.

The Sensitiveness of the Heart Muscle to Increase in Diastolic Filling—If the resistance against which the heart contracts is increased as by partially occluding the aorta, a compensation of car-

diac output will occur which will eventually result in an unchanged arterial blood pressure. It was formerly thought that this compensation represented a response on the part of the heart to an increase of tension, but the increased output of the heart under these conditions has been found to be always associated with an increased capacity of the ventricle, with, in other words, a dilatation of the ventricle and increased diastolic filling. It is found, however, that this dilatation of the ventricle is not accompanied with an increase of intraventricular pressure during diastole. In fact, the intraventricular pressure may be approximately zero at the end of diastole, whether the heart is beating against 80 mm. pressure or 120 mm. pressure. When, however, the heart is required to meet the demands of a higher arterial pressure, it does so at an increased systolic pressure in order to force the normal quota of blood out through the aorta. It then meets the increased aortic pressure by an increased systolic force exerted upon an increased quantity of blood within it. (Fig. 70.) The increased quantity of blood contained within it, however, does not mean that the fibers of the heart muscle are subjected to an increased tension, but are only increased in length. The increased response of the heart to the increased resistance by an increase of the length of its fibers is a function of the cardiac muscle and is the determining factor in its ability to respond to increased demands upon it.

Effect of Temperature on Heart Muscle—A rise of temperature will increase the frequency of the heart beat. The mammalian heart will beat four times as frequently at 40° C. as at 15° C.

Various salts produce a stimulating effect on heart muscle. For any continued contractions to take place it must be surrounded in a fluid of an osmotic pressure equal to that of the blood. The excised apex of the tortoise heart will not contract, but immersion of its isolated apex in sodium chlorid solution will cause it to contract rhythmically for a long time. It finally stops in a condition of relaxation. The addition now of a trace of calcium chlorid to the solution will again cause contractions for a time. This time the heart ceases to beat in a contracted state. Again the apex can be made to beat by adding a trace of potassium chlorid or phosphate and it will continue beating for many hours. The first effect of the potassium salts has been to produce relaxation of the contracted apex.

The Effect of Changes in the Reaction of the Blood and of Varying Percentages of Carbon Dioxid upon the Action of the Heart—Perfusion of the heart with weak acids produces a decrease in the tonus of the heart. The contractions are less forcible and extensive and finally disappear. Weak alkalis produce the opposite effect. The collection of excessive quantities of carbon dioxid will produce the same effect as weak acids. There is unquestionably a mean between alkalinity and acidity which is most favorable to the action of the heart. In so far as carbon dioxid concerns this

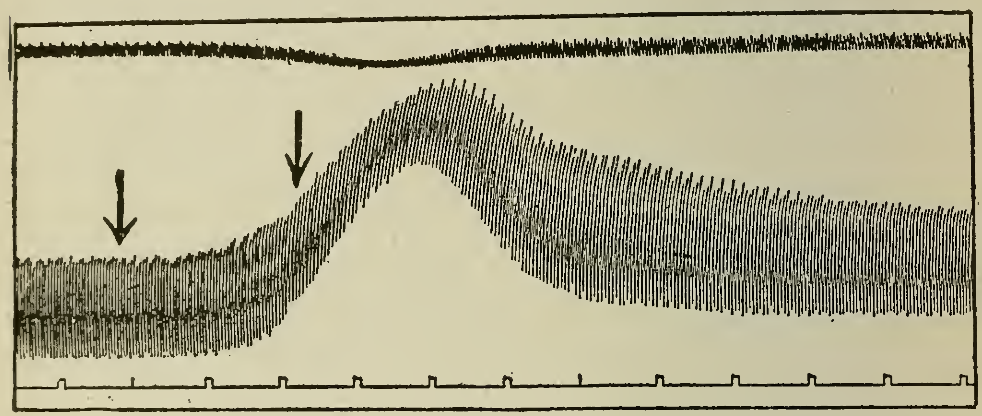


Fig. 71.—Volume Curve of Ventricles (Cat; Lower Curve).

The upper curve is the arterial pressure, maintained by an adjustable resistance at 130 mm. Hg. Between the arrows the air used for artificial respiration was replaced by a mixture containing 20 per cent. CO_2 and 25 per cent. oxygen. Note the dilatation with impaired contraction, followed by increased amplitude of contraction. Each down stroke in lower curve represents ventricular contraction. (Starling.)

optimal mean is represented by 5–6 per cent. of an atmosphere of CO_2. The decrease of tonus, accompanied by dilatation of the ventricle and impaired contraction, is represented by Fig. 71.

The Nutrition of the Heart—The heart is nourished by the circulation of blood through the coronary arteries. These arteries terminate in capillaries which supply all parts of the heart muscle. The coronary arteries do not anastomose with each other. They are, therefore, called terminal arteries. Any obstruction to the flow of blood through a branch of a coronary artery, as, for instance, a blood clot, will cause the death of a certain section of heart muscle. The effect of such an accident is almost immediate. This portion of the heart becomes non-conductive. The heart continues beating for one or two minutes; then a beat is occasionally

dropped, and finally the heart stops altogether. At the time when the heart stops it passes into a state of fibrillar contractions, often called delirium cordis, in which state various portions of the heart contract more or less rhythmically without coordination or any sequence. It becomes incapable of carrying on the circulation. A collection of the metabolites resulting from cardiac activity will increase within certain limits the flow of blood through the coronary arteries. Thus the flow of blood through the coronary arteries has been increased from 56 cc. per minute to 180 cc. during a period of asphyxia before the heart failed. The heart therefore contains within itself a mechanism for assisting in the getting rid of the deleterious products of its own activity and of the activity of other muscles. These metabolites are not alone carbon dioxid, because it is impossible with this gas alone to produce the increased flow of blood which is observed in asphyxia.

The Nervous Control of the Heart's Action—In order that the heart may meet the varying needs of the body for a more rapid or slower circulation it is necessary that some mechanism should exist which is capable of producing changes in the action of the heart in response to messages from various portions of the human body. Such changes are also quite as necessary for the sake of the heart itself, in order that it may protect itself, in the presence of excessive demands on the vascular system, against an activity which would quickly exhaust it.

The Nerve Supply of the Heart—The heart receives nerves from the vagus nerve and from the sympathetic nerves. The cardiac nerves of the vagus are axons of cells underlying the ala cinerea of the floor of the fourth ventricle. They leave the trunk of the vagus nerve in the neck and pass as medullated fibers to the heart, where they end around the cells of Remak's ganglion. Non-medullated fibers, the axons of the cells of Remak's ganglion, continue the impulses onward to the cardiac muscle.

In the dog the sympathetic cardiac nerves leave the spinal cord in second and third dorsal nerves (upper fourth or fifth dorsal nerves in the human being). They pass as white rami communicantes to the corresponding thoracic ganglia, and through these to the stellate ganglion. Here they end around cells the axons of which are non-medullated fibers and continue the impulses onward through the inferior cervical ganglion. From these two ganglia the

stellate ganglion and the inferior cervical sympathetic ganglion, and in man from the superior and middle cervical ganglia as well, the nerves pass as non-medullated nerves to the heart. It is possible by the nicotin method to identify exactly the situation of the ganglionic cell station of these nerves.

The Effect of Division and Peripheral Stimulation of the Vagus Nerve—What impulses are transmitted to the heart by the vagus

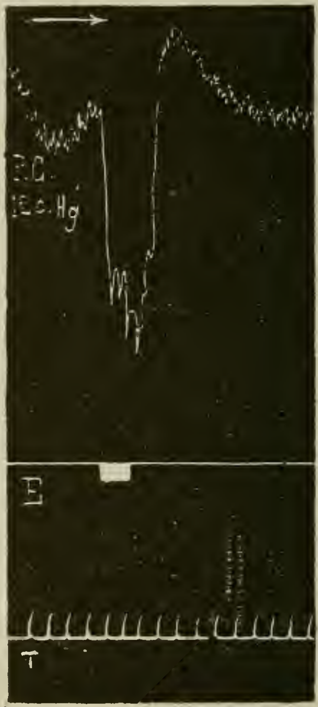


FIG. 72.—ARREST OF THE HEART OF A RABBIT PRODUCED BY STIMULATION OF THE PERIPHERAL END OF ONE PNEUMOGASTRIC.

At P.C. the carotid blood pressure was 12 cm. of Hg. E indicated application of stimulus of an induced current, time indicated by lowest tracing in 2 seconds.

nerve? Stimulation of the divided peripheral vagus nerve will cause the heart to become slower, and in consequence of increased diastolic filling more forcible. If the stimulation is continued the heart will stop altogether. (Fig. 72.) Due to the slowing of the heart, the blood pressure falls. After the cessation of the stimulus the heart will begin to beat again, and harder than ever. So also the blood pressure may rise above normal. These reactionary effects are due to the collection of carbon dioxid in the blood. The

carbon dioxid also stimulates respiration, an effect which also aids the circulation in the manner previously explained.

If the stimulation of the peripheral end of the vagus is not too strong even during the period of stimulation, the heart may begin to beat again. Such a recovery is spoken of as an escape of the heart from the influences of the vagus. During such an escape,

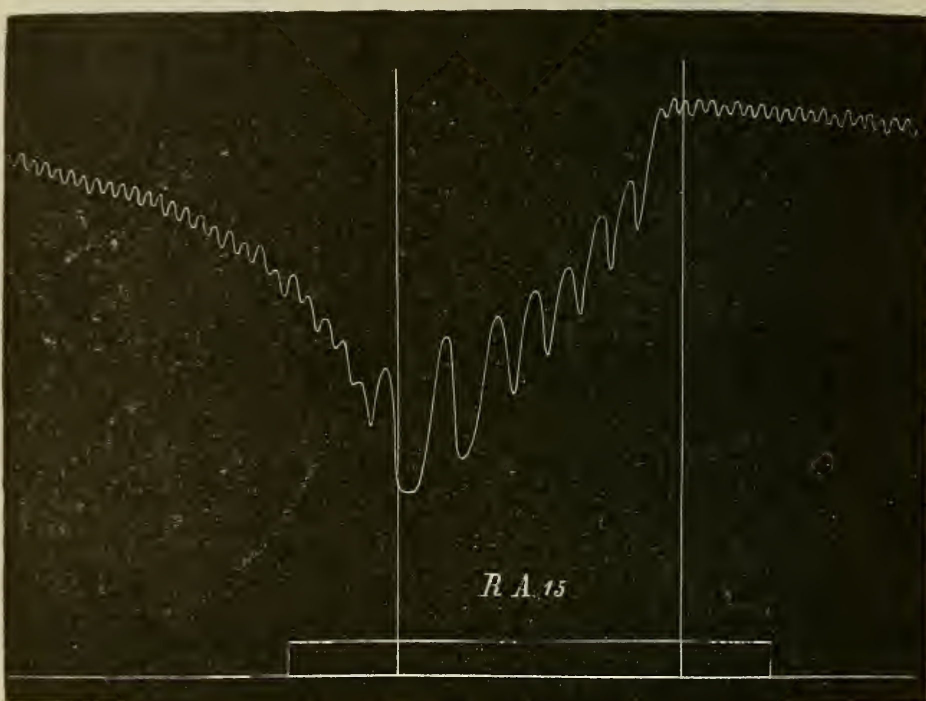


FIG. 73.—THE EFFECT ON THE BLOOD PRESSURE CURVE OF STIMULATION OF THE VAGUS NERVE.

The tracing is to be read from left to right. The period of stimulation is indicated by the vertical lines. (Robert Tigerstedt.)

however, the cardiac contractions are purely ventricular in character. Any normally augmentatory factor, as an increase of diastolic filling of the ventricle, will favor this escape. The slowing of the heart will increase the diastolic period and, therefore, the filling of the ventricle and in consequence the cardiac output.

The Different Effect Exerted through the Vagus upon the Heart When Its Impulses Act upon the Sino-auricular Node or Directly upon the Auricles—The vagus may either affect the heart through the region of the heart which contains the sino-auricular node or act on the auricles directly. In the former case the rhythm

of the heart is (S. venosus) slowed (Fig. 73) while in the latter instance the rhythm is not affected, but the auricular contractions are much weaker. The auricular contractions may be so reduced that they cannot be recorded. As long, however, as there is any contraction in the auricles the rhythm of the ventricles will coincide with that of the auricles. Generally stimulation of the peripheral end of the vagus will cause an entire cessation of the auricular contraction. In this case the ventricles also cease beating. Not infrequently the ventricles will begin beating again after a pause and with a slow, apparently with an independent, rhythm of their own.

Evidence That the Vagus Directly Affects the Muscular Tissue of the Ventricles—When under the conditions described in the last paragraph the contractions of the ventricles again begin they may inaugurate a reversal beat in the heart; and this fact shows that the ventricles are inaugurating their own contractions. It is probable that in the mammalian heart the vagus produces some slight direct effect on the ventricles, because stimulation of the vagus produces a temporary cessation of the ventricular contractions, while functional separation of the ventricle from the auricle produces no such temporary stoppage. The vagus at other times may affect the auriculo-ventricular bundle, producing a block. The auricles may then beat faster than the ventricles.

To sum up, the vagus contains fibers which produce an inhibitory action on the sino-auricular node. This is the most important function of the vagus and effects the rhythm of the heart alone. It also contains fibers acting on the auricles and on the ventricles themselves. These effects are limited to the strength of the contractions.

The effect upon the heart through the vagus is a direct one upon muscular fibers themselves, and not a result of any independent activity of the cells of Remak's ganglia.

Many facts support this view, among them the following:

1. A weak tetanizing current applied to the heart will cause a relaxation (inhibition) of the heart muscle between the points of application of the electrodes.

2. Nicotin will prevent the effect upon the heart ordinarily caused by a peripheral stimulation of the vagus nerve.

3. The usual effects upon the heart from stimulation of the

vagus nerve may be produced whether the pre- or postganglionic fibers are stimulated.

4. Muscarine, a drug which stimulates the inhibitory fibers of the vagus, produces weakening of the heart when painted in solution either on the auricle or ventricle.

The Essential Nature of Such an Inhibitory Process—The essential nature of an inhibitory process has been explained in two ways.

According to one view it is simply a prolongation of the period of rest. The assumption is justified that anabolic changes occur in every tissue during rest. Certainly activity is associated with tissue disintegration or katabolism, and when activity is over a building up process or replacement of the broken down products must occur. This building up, or anabolism, must leave the tissue with more potential power after the inhibitory periods as experiments demonstrate it to have. At any rate, as long as anabolism is taking place the tissue cannot be active.

According to the second view the inhibitory impulses actually stimulate or produce anabolism within the tissues. Inasmuch as every activity of a tissue or every katabolic change is associated with an electrical change of such a character that the point of greatest activity becomes negative, we would expect that inhibition would be accomplished with a difference of potential of the opposite character, and, as a matter of fact, during inhibition the point of reception of the inhibitory impulses becomes positive to other points. There is, in other words, an increase of the resting or demarcation current.

The Activity of the Vagus Mechanism During the Normal State—During the normal state of any animal tonic or constant inhibitory impulses are constantly descending the vagi nerves to the heart. This fact is demonstrated by the increase of frequency of the heart beat which follows the division of both vagi nerves. This effect varies much with different animals. Morphin will augment these constant inhibitory impulses.

Action of Adrenalin upon the Heart—In connection with a description of the cardiac functions of the vagus nerve it is desirable to consider the action of adrenalin upon the heart. The blood normally contains a definite quantity of this substance, and it possesses an important stimulant action upon the heart which is identical

with the effect produced by stimulating the sympathetic nerves. Whereas, however, adrenalin produces a contraction of all vessels in the body supplied with sympathetic fibers, it produces a dilata-

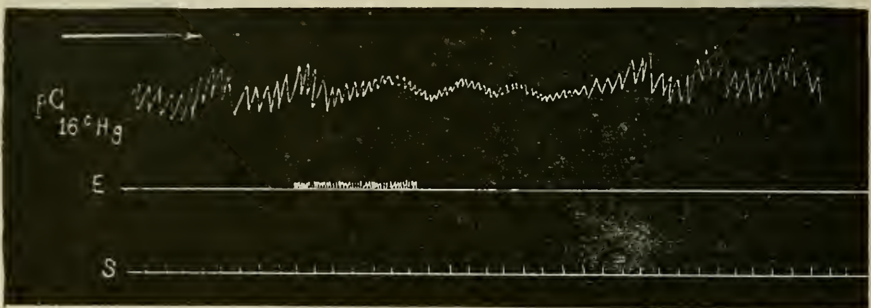


Fig. 74.—Increase in the Frequency of the Heart Beat Following Stimulation of an Efferent Branch of the First Thoracic Sympathetic Ganglion.

Experiment on a curarized dog.

PC, carotid blood pressure; E, period of stimulation of the nerve by an induced current; S, time in seconds. (Elgley.)

tion of the coronary vessels, serving, therefore, admirably in virtue of this associated action to increase the rate and force of the heart beat.

The Function of the Cardiac Sympathetic Nerves—The Effect of Peripheral Stimulation—*The Action of the Sympathetic Cardiac Nerves*—The sympathetic cardiac nerves are the normal antagonists

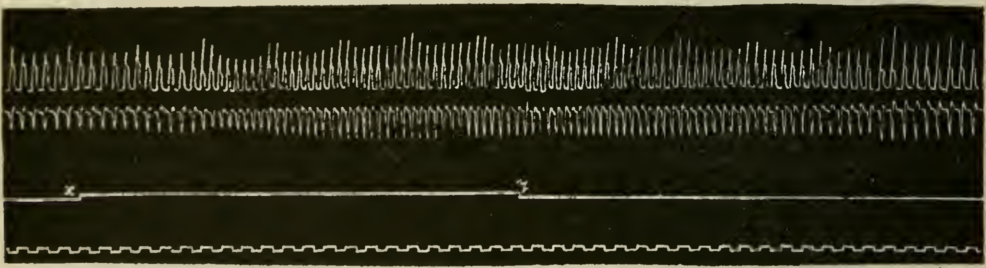


Fig. 75.—Tracing of Ventricular (Upper Curve) and Auricular Contractions (Lower Curve).

From x to y, the accelerator nerves stimulated. Lowest line = seconds. (Starling.)

of the vagi. Peripheral stimulation of the sympathetic nerves will increase the frequency of the heart beat. Usually the strength of the auricular and ventricular contractions is also increased. (Figs. 74 and 75.)

The Combined Effects of Peripheral, Vagus and Sympathetic Stimulation—While the latent period of the effect of vagus stimulation on the heart is only one or two seconds, the latent period of the sympathetic stimulation is 10, or even 20, seconds. When,

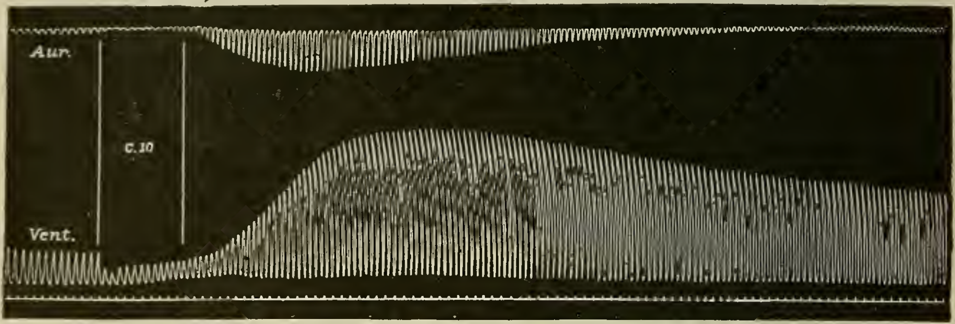


Fig. 76.—Tracing to Show the Primary Inhibitory Effect and Secondary Augmentatory Effect upon the Beats of the Auricles and Ventricles of the Frog's Heart, Obtained by Stimulating the Vagosympathetic Nerve in the Neck.

The rate is unaltered. Suspension method with the clamp in the auriculoventricular groove.

therefore, both nerves are peripherally stimulated the first effect would be a vagus effect, which becomes fatigued about the time that the sympathetic effect come on. (Figs. 76 and 77.) Like the vagus, the sympathetic nerve produces an augmentative influence on the

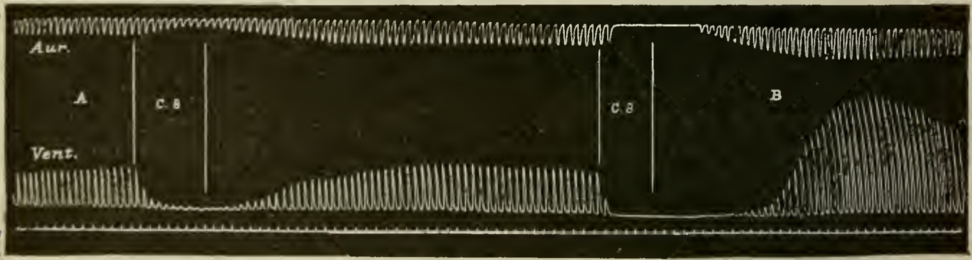


Fig. 77.—Tracing of Heart-Beat of Frog.

Suspension method clamp in auriculoventricular groove. Stimulation of the vagus in the neck (i.e., the combined vagus and sympathetic nerve), showing the effect of the simultaneous stimulation of the two nerves, namely, a primary complete inhibition followed by augmentation. (E. A. Schäfer.)

heart. Excision of the stellate ganglion causes slowing of the heart.

The Afferent Channel for the Nervous Impulses Affecting the Heart and the Cardiac Center—*The Afferent Channel*—The vagus

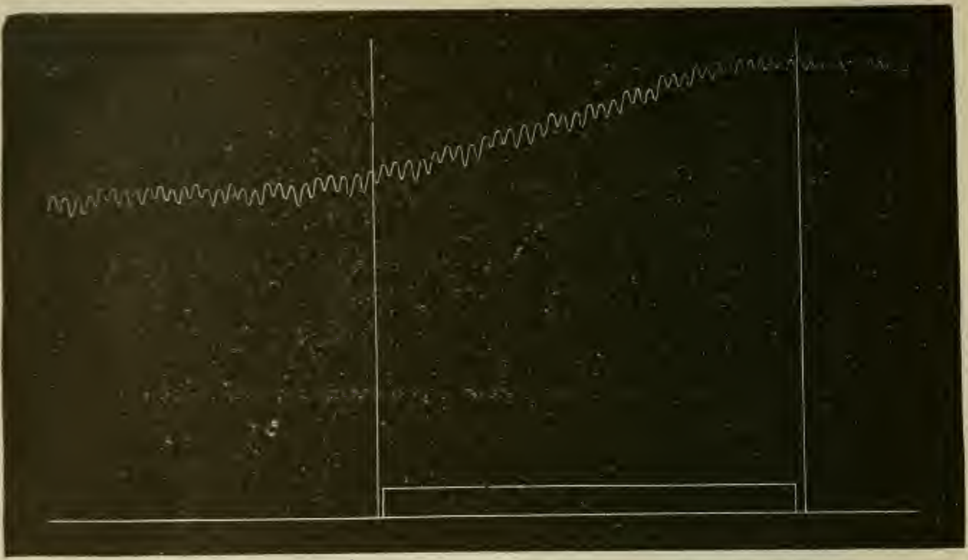


FIG. 78.—REFLEX FALL OF PRESSURE AFTER STIMULATION OF AN AFFERENT MUSCULAR NERVE IN A RABBIT.

The tracing is to be read from right to left. The duration of the stimulus was 10 sec. and is indicated by the raised horizontal line joined at its ends to the base line. (Robert Tigerstedt.)

and sympathetic nerves to the heart are only half of the mechanism for the regulation of the heart's activity. The other half concerns the afferent channels.

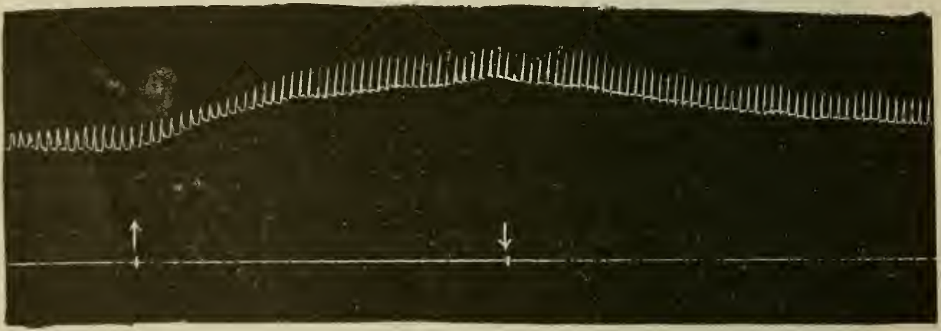


FIG. 79.—BLOOD-PRESSURE CURVE FROM CAROTID OF DOG.

Between the arrows the central end of a sensory nerve was stimulated. (Starling.)

In other words, the heart's action cannot change to meet varying conditions in the body without provision for the transmission of afferent impulses from other regions of the body into efferent impulses. (Figs. 78, 79 and 80.) Unquestionably the common meet-

ing place of these impulses is in the medulla; the efferent vagus fibers to the heart are axons of cells in the ala cinerea of the floor of the fourth ventricle.

Though the sympathetic fibers are axons of cells in the lateral horn of the spinal cord of the upper dorsal region, these cells are unquestionably directly under the control of the medullary centers.

The most important afferent cardiac nerves run to the medulla in the vagus nerve from the heart itself and the aorta. In the mammalian heart fibers can be seen upon the surface of the ven-

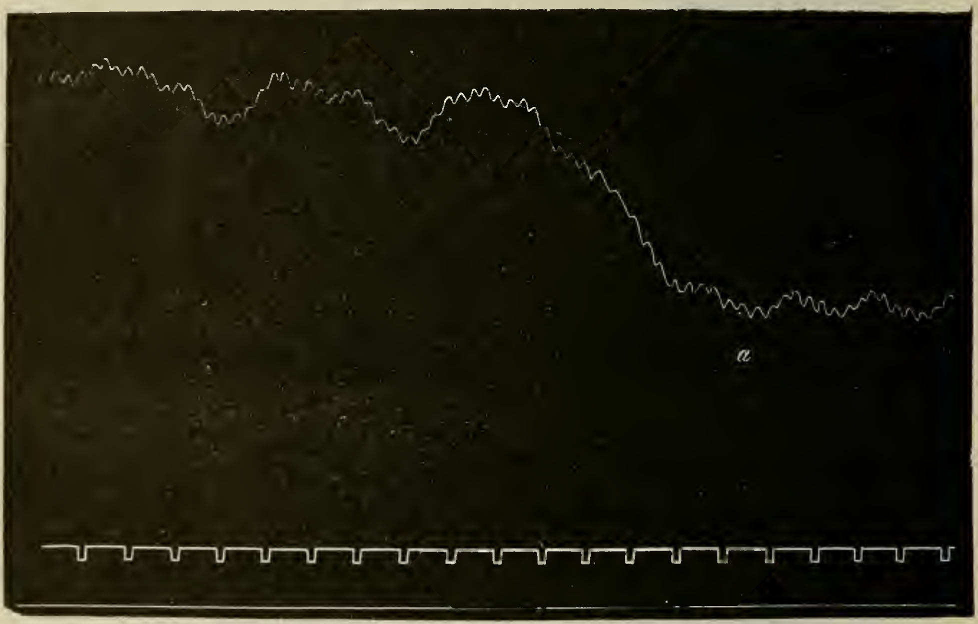


Fig. 80.—Reflex Increase of Blood Pressure in Rabbits Produced by Irritation of the Skin.

Tracing is to be read from right to left. (Robert Tigerstedt.)

tricle. Stimulation of their central end produces any one of the following results:

1. Slowing of the heart.

2. Rise of blood pressure from constriction of the splanchnic area.

3. Fall of blood pressure due to dilatation of the arteries of the body.

Pathological lesions of the heart may be accompanied with pain. The heart, therefore, is supplied with sensory nerves.

A. The Depressor Nerve—In the rabbit these depressor fibers

form two separate nerves coming off from the trunk of the vagus and the superior laryngeal nerve. It runs up to these portions of the vagus from the cardiac plexus of nerves.

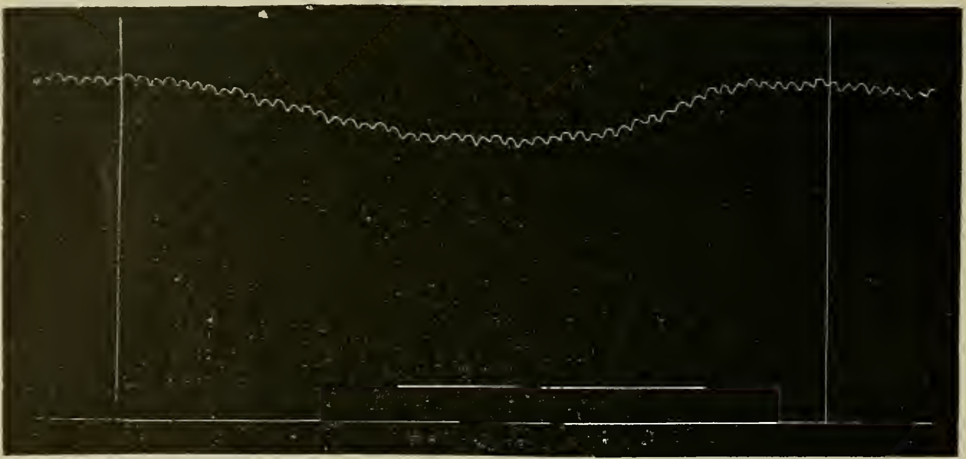


FIG. 81.—THE BLOOD PRESSURE CURVE AFTER ELECTRICAL STIMULATION OF THE DEPRESSOR NERVE.

The tracing is to be read from right to left. The period of stimulation is indicated by elevated horizontal line joined by two vertical lines to the base line. The period lasted 10 sec. (Robert Tigerstedt.)

B. The Afferent Paths for "Depressor" Impulses—Stimulation of its peripheral end is without effect, but stimulation of its central end produces a great fall of blood pressure. (Figs. 81, 82, and 83.)

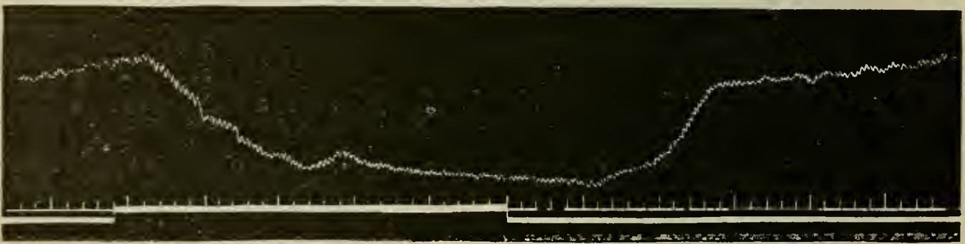


FIG. 82.—EXCITATION OF THE CENTRAL END OF THE DEPRESSOR NERVE OF RABBIT.

Fall of blood-pressure due to reflex relaxation of the splanchnic vessels. (N.B. The vagus was uncut, hence the fall is associated with reflex slowing of the heart-beat. The abscissa has been raised 3 cm.) (Waller.)

C. The Efferent Paths of the Depressor Nerve and the Two Factors Concerned in the Depressor Effect—This fall of blood pressure is caused by the stimulation of two kinds of efferent impulses

resulting from the afferent impulses passing to the medulla along the depressor nerve.

One kind of efferent impulse descends through the cardiac vagus nerves and causes a slowing of the heart. These are prevented by a section of the vagi. The other kind descends to all the blood vessels of the body, causing a universal vascular dilatation, especially of the splanchnic area.

D. The Peripheral Termination of the Depressor Nerve and the Significance of Such an Ending—The cardiac plexus to which this

Fig. 83.—Tracing of the Arterial Pressure as Effected by Stimulation of the Central End of the Depressor Nerve in a Rabbit.

Time in 2 sec. (E. Grey, "Traite elementarie de physiologie.")

nerve runs is in intimate relation to the aorta. Any increase of pressure in the aorta is capable of stimulating the depressor nerve so that it forms one of the important means by which the heart may be relieved of excessive pressure. Currents of action have been detected in this nerve when the aortic pressure is high.

The Nature of Other Afferent Paths in the Vagus Nerve—Other afferent nerves ascend to the medulla through the vagus which are related to the cardiac reflexes.

Stimulation of the central end of the vagus generally causes a slowing of the heart's action. Many of the fibers responsible for this effect have their peripheral termination in the lungs.

Inflation of the lungs is said to cause an acceleration of the

heart's action. Whether these afferent impulses cause an inhibition of the vagus or a stimulation of the sympathetic is not known.

The Relation of the Rate of the Heart to Blood Pressure—Of great importance is the definite relation of blood pressure to the rate of the heart beat. The blood pressure with few exceptions, as during exercise, varies inversely as the heart rate. All the paths of this reflex are not known.

The Effect of Exercise on the Heart Beat and on Blood Pressure—Muscular exercise increases the rate and force of the heart beat and the blood pressure.

The following factors are the cause of these two changes:

1. The effect of increased carbon dioxid and lactic acid on the blood vessels and these and other metabolites on the coronary circulation.

2. An increase in the frequency and force of respiration.

3. An increase in the return of the blood to the heart, due to the contractions of the voluntary muscles.

4. Through attention there results a reflex effect from the cortical centers upon the medullary centers which results in a rise of the blood pressure by a contraction of the splanchnic area, and the rise bears a direct relation to the injurious effects of exercise after eating.

5. The increased secretion of adrenalin.

6. The blood pressure is also raised by the action of the carbon dioxid on the medullary vasomotor center. Within the contracting voluntary muscles the vessels are dilated. It is also possible by means of central reflexes through the cardiac center in the medulla that the primary inhibitory effect upon the vasomotor center through the vagus during exercise may be switched off upon the accelerator efferent nerves so that reflexly the heart becomes more rapid in force and frequency.

7. Some accelerator effect depends upon the rise of body temperature.

Explanation of Second Wind—After exercise has been in progress the first sense of exhaustion is followed by relief. This relief is called second wind. It depends upon the following factors:

1. Dilatation of the vessels in the contracting muscles, due to the discharge of metabolites in them.

2. A diminution in the respiratory quotient; more oxygen is

taken in by the body in proportion to the carbon dioxid given off from the body.

3. An improvement in the coronary circulation and a response by the heart in virtue of its power of accommodation to the increased blood pressure. The heart always responds to a higher blood pressure. As the blood pressure rises by successive steps the heart maintains the same output. (Fig. 84.)

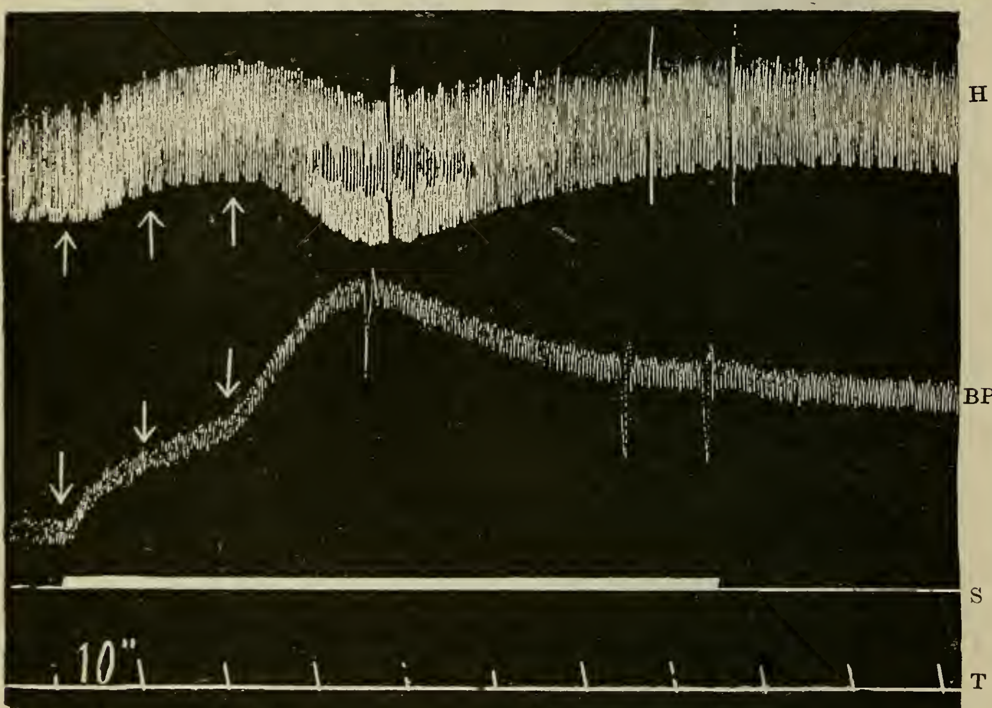


Fig. 84.—Curve Showing the Effect of a Sudden Rise in the Arterial Resistance on the Output and Volume of the Ventricles.

Systole causes a downward movement of the lever of the cardiometer. H, heart volume; BP, arterial blood-pressure; S, signal showing duration of stimulation of splanchnic nerve; T, time-marker, 10 sec. (Starling.)

Nervous Control of the Blood Vessels—The Necessity for Its Existence—While an increase in the force and frequency of the heart will supply more blood to the general capillaries of the body, such a means of furnishing more blood to actively functionating tissues as the muscles or glands is totally inadequate. Some means must exist for increase of the blood supply to those organs where it is most needed without interfering with the general blood supply to the body at large. During active muscular exercise the me-

tabolism of the whole body may be increased five to six times. Most of this increased metabolism is going on in the muscles. A provision exists for taking the blood from, for instance, the digestive system where it is not needed and increasing the flow through the muscles where it is most needed. This change in the distribution of the blood is chiefly accomplished through the nerves which supply the walls of the blood vessels. It is in part accomplished through local chemical changes.

The Portion of the Nervous System Responsible for the Control of Blood Pressure—That portion of the nervous system which is chiefly concerned in the control over the distribution of the blood in the body is the sympathetic nervous system.

THE SYMPATHETIC NERVOUS SYSTEM

The sympathetic nervous system consists of a chain of ganglia connected with each other and lying parallel to the vertebral column. There is in general a ganglion for each spinal nerve, at least in the dorsal and lumbar region of the spinal cord. In the cervical region the ganglion corresponding to each spinal nerve is collected into three ganglia, the superior, middle and inferior cervical ganglia. The inferior cervical sympathetic ganglion is connected by two cords, which surround the subclavian artery, with a large ganglion below the subclavian artery, which is called the stellate ganglion. The ring formed by the two cords surrounding the subclavian artery is called the ansa or annulus of Vieussens.

These various ganglia receive nerves which are branches of the anterior spinal nerves from the first dorsal to the third or fourth lumbar, and are all connected to each other by a double cord. The stellate ganglia receive branches from the upper fourth or fifth dorsal nerves. Many of these are continued through into the superior middle and inferior cervical ganglia.

The nerves connecting the anterior spinal nerves with the sympathetic ganglia are called rami communicantes. They are of two kinds, gray and white rami. The white rami are medullated, while the gray are not. The white rami represent those nerves which are axis cylinders of nerve cells in the lateral portion of the gray matter of the spinal cord near the level of the anterior root, with

which the white rami emerge from the cord. All white rami end around some of the ganglion cells of the sympathetic system. The impulses of the white rami are continued on by the axons of the ganglionic cells. These axons are always non-medullated; they are called postganglionic fibers. The gray rami are simply postgan-

FIG. 85.—SHOWING THE INCREASED VASCULARITY IN THE RABBIT'S EAR PRODUCED BY DIVIDING THE SYMPATHETIC NERVES TO THE RIGHT EAR.

(This animal was in shock at the time of the division.)

glionic fibers which have rejoined the spinal nerves to issue at a different level. We have already described the branches of the sympathetic nerves to the heart.

Effect of Peripheral Stimulation—When these nerves are stimulated the blood vessels which are supplied by them contract. The noted experiment which demonstrates their function consists in

the division of the cervical sympathetic of a rabbit on one side of the neck. Immediately the vessels of the head and neck, but particularly those of the ear, because they show the changes so well, will dilate. (Fig. 85.) Vessels in the ear which were previously invisible become now visible and the whole ear redder. If now the peripheral divided end is stimulated, the vessels of the ear once more contract. This experiment demonstrates clearly that the sympathetic nerves carry vasoconstrictor impulses to the blood vessels.

The Normal Starting Place of Vasoconstrictor Impulses—Do these impulses originate in the cells of the spinal cord, from which the white rami of the sympathetic system originate, or higher up? We can only decide by dividing the cord at a higher level. Let us divide the cord at the level of the first dorsal nerve. Immediately following this section there will be a great fall of arterial blood pressure throughout the body. It may even fall from 120 mm. of Hg. to 40 or 50 mm. Hg. The heart will beat more rapidly in an attempt to compensate for the fall of blood pressure, so that the low pressure is entirely due to the loss of vasomotor impulses, which normally are constantly passing along the sympathetic nerves to the blood vessels.

These impulses, therefore, must originate somewhere in the nervous system above the spinal cord. If the upper extremity of lower segment of the divided spinal cord is stimulated the blood pressure will rise once more.

If now we divide the brain above the medulla oblongata there will be no fall in blood pressure. The vasoconstrictor impulses must, therefore, originate in the medulla oblongata. Moreover, their exact site of origin in the medulla can be identified with a region in the floor of the fourth ventricle lateral to the middle line and on a level with the origin of the facial nerve. This region represents the continuation forward of the lateral columns of the spinal cord after the pyramidal tracts have left the lateral columns to form the decussation of the pyramids. A destruction of this region of the medulla will cause the same general fall in blood pressure. This region is called the vasomotor center.

Significance of the Term Center, as Applied to This Starting Place—The use of the term center, however, must not be construed to mean a region which originates vasoconstrictor impulses. It is

quite true that the impulses do start in this center, yet the center does not originate them in the sense of creating them "de novo."

The vasomotor center, as all other medullary centers, is simply the meeting place of impulses coming to the center along other nerves from various portions of the body—portions of the body which may at any time be in need of vascular changes. The impulses from the periphery, afferent impulses as they are termed, come whenever there may be need of vasoconstriction, and may be conceived of as stimulating the vasomotor center to send out impulses to the periphery, efferent impulses as they are called, which cause constriction of the blood vessels. Again other impulses along other afferent nerves may check or inhibit the normal vasoconstrictor impulses, those which are constantly outflowing from the vasoconstrictor center, and which maintain the normal degree of constriction in the blood vessels. When these other afferent nerves act we have inhibition of the vasomotor center and a consequent dilatation of the blood vessels.

The vasomotor center, then, is the place where efferent vasomotor impulses originate, a place which can be played upon by impulses along different nerves, which impulses cause it to react according to the needs of the body.

The Effect of the Lack of Oxygen and Increased Carbon Dioxid on the Vasomotor Center—The vasomotor center is not alone played upon by nervous impulses. It is strongly affected by changes in the character of the blood. The effect of these changes upon it may be demonstrated by the administration of curare. Curare paralyzes all motor-end plates so that no striped muscle is capable of contracting. Respiration is, therefore, stopped by it. The animal obtains no fresh oxygen and carbon dioxid accumulates within its blood. The effect of these two changes in the blood, a deficiency of oxygen and an accumulation of carbon dioxid, may now be studied.

It is better at first to eliminate any reflex action upon the heart through the vagus nerve by dividing it. As soon as artificial respiration is stopped the blood pressure remains unchanged for 20 to 50 seconds. It then rises rapidly and in 10 seconds more may reach a height twice as great as previously.

The blood pressure remains at this height for one minute and then gradually falls. This fall is due to failure of the heart to continue its contractions against the high blood pressure. That

such is the case may be easily proved by excising the heart quickly, when it will again begin to beat, or by beginning artificial respiration while the blood pressure is falling. As soon as the heart is once again supplied with oxygen it will begin once more to contract, even though the blood pressure would have risen still higher. To what is the rise in the blood pressure during asphyxia due? It is due to the lack of oxygen or to the excess of carbon dioxid.

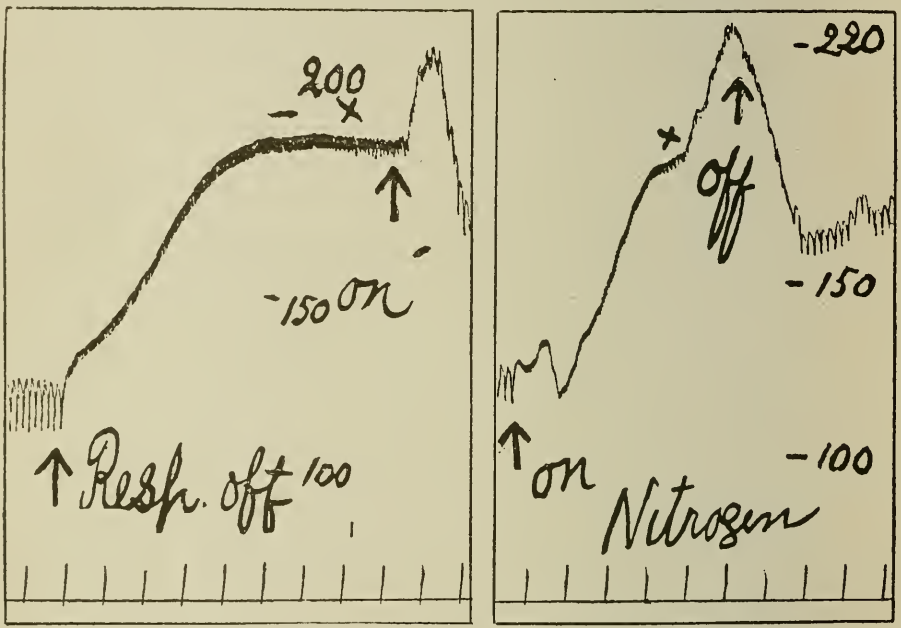


FIG. 86.—IN THIS AND THE FOLLOWING EXPERIMENT THE CAT WAS DECEREBRATED BY A DIVISION OF THE BRAIN STEM JUST ABOVE THE ANTERIOR CORPORA QUADRIGEMINA, BOTH VAGI WERE CUT AND THE ANIMAL CURARIZED.

In A simply the artificial respiration was discontinued. There occurs a rise of blood pressure to over 200 mm. of mercury.

The experiment illustrates the effect on the vasomotor center of a combination excess of CO_2 in the blood and an oxygen lack.

N. B. The artificial respiration is continued with pure nitrogen alone. There occurs quite as high a rise in blood pressure, which in this case depends alone on an oxygen lack.

We must test each separately by respiring an animal in the first place with some indifferent gas such as nitrogen or hydrogen, in which case the animal will suffer from the lack of oxygen, but will rid its blood of carbon dioxid; and in the second place by respiring the animal with carbon dioxid containing a large percentage of oxygen; in which case the animal will obtain sufficient oxygen, but will store up within its blood an excess of carbon dioxid.

Such experiments demonstrate that both a diminution of oxygen and an excess of carbon dioxid will stimulate the vasomotor centers, the effect coming on more quickly when due to an excess of carbon dioxid. (Figs. 86, 87 and 88.)

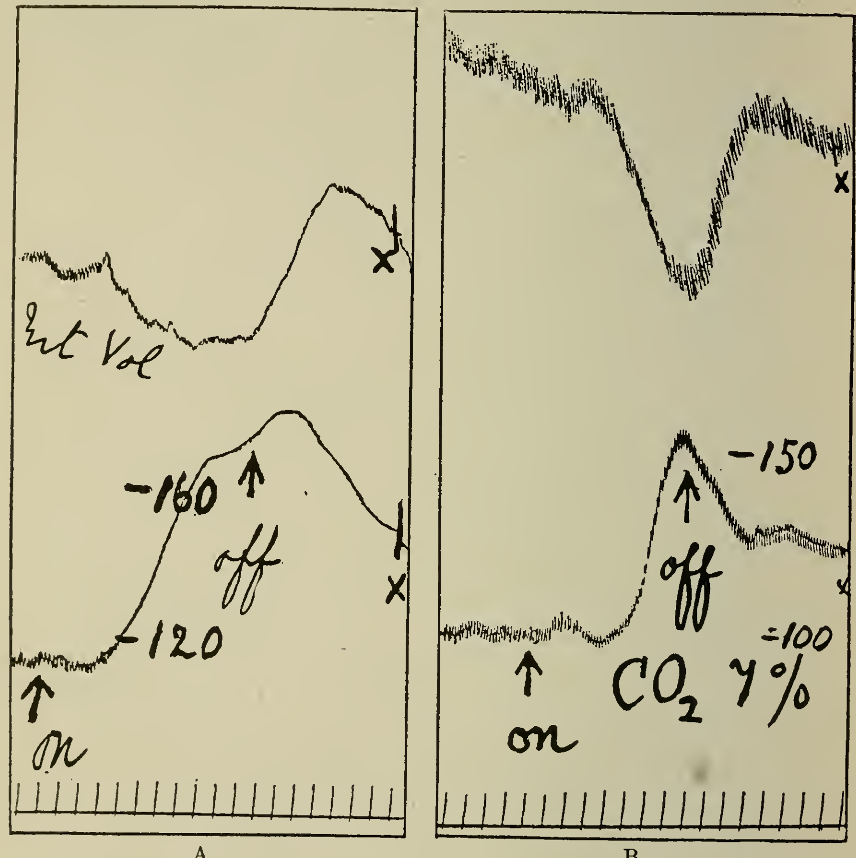


FIG. 87.—SAME PREPARATION AS IN THE PREVIOUS EXPERIMENT, I.E., CAT DECEREBRATED, CURARIZED AND BOTH VAGI CUT.

In A artificially respired between the arrows with a mixture of 4.7 per cent. CO_2 and 20 per cent. O_2. The experiment illustrates the effect of an excess of carbon dioxid in the absence of oxygen. The blood rises and the intestinal volume diminishes, but neither to the degree as in the previous experiment.

In B the animal is respired with 7 per cent. CO_2 and 25 per cent. O_2 with little increase in the height to which the blood pressure rose.

Effect of Increase of Lactic Acid on the Vasomotor Center— Another factor must also be considered. Any muscular exertion in the absence of sufficient oxygen is accompanied by the accumulation of lactic acid in the blood. The injection of lactic acid into the circulation will of itself cause a rise of blood pressure.

In ordinary asphyxia, therefore, three factors are certainly involved:

1. A diminution of oxygen.
2. An accumulation of carbon dioxid.
3. An accumulation of lactic acid.

All stimulate the vasomotor center.

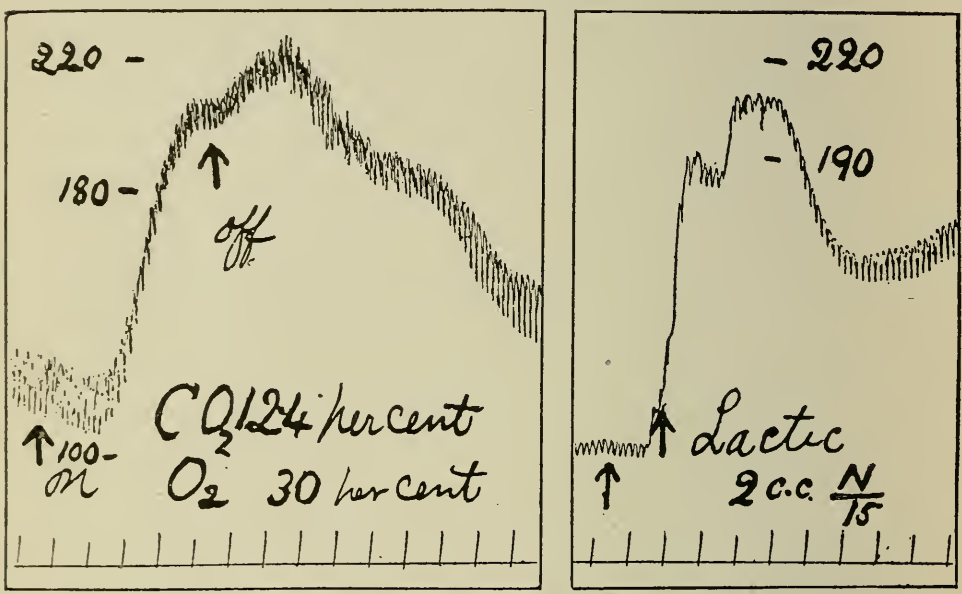


Fig. 88.—In These Experiments the Cat Received the Same Preliminary Treatment, i.e., Rendered Decerebrate, Curarized and Both Vagi Cut.

In A the animal was respired with 12.4 per cent. CO_2 and 30 per cent. O_2. In this animal the blood pressure arose quite as high as in the first asphyxia experiment, so that such excessive amounts of CO_2 are efficient even in the absence of oxygen lack.

N. B. The cat received intravenously 2 cc. of $\frac{N}{15}$ or 6 per cent. lactic acid solution, artificial respiration being continued.

The blood pressure was increased about as much by this procedure as by CO_2 excess or oxygen lack, demonstrating that in all three of these experiments there is a common factor, an excess of the hydrogen ions in the blood, which is responsible for the effect.

The Antagonistic Effect Exerted through the Vagus to Excessive Chemical Effects on the Vasomotor Center—Thus far we have considered the effects of asphyxia on the vasomotor center undisturbed by any other influences upon the heart through the vagus nerve. If the animal is allowed to pass into asphyxia in the same manner by withholding artificial respiration during poisoning

with curare, without a division of the vagus, the same effects will be produced, but they will be more gradual and prolonged.

Through the vagus center the heart will be inhibited. Its action will be slower, and consequently the blood pressure will not rise so rapidly. The final heart failure will be postponed because of its slower action. Two causes act upon the vagal cardio-inhibitory center.

The Two Factors Involved—The first is the accumulation of carbon dioxid. This gas stimulates the vagal cardio-inhibitory center as well as the vasomotor center. Secondly, on account of the increased blood pressure the tension within the unyielding cranial cavity is increased. The increased intracranial pressure further stimulates the vagal cardio-inhibitory center.

The Traube Hering Waves—During the period of increased blood pressure resulting from asphyxia two kinds of waves appear on the blood pressure curve.

One kind of these waves is the respiratory wave. It is formed of elevations and depressions of the blood pressure curve occurring at regular intervals with the pulse wave, and are in part due to increased pulmonary capacity accompanying inspiration, but in the opinion of many are in part due to irradiation of impulses from the excited respiratory center to the vasomotor center in the medulla. (Fig. 89.) Even a single twitch of the diaphragm, insufficient in itself to cause any mechanical effect upon the circulation, may be observed to accompany each rise in the blood pressure curve.

Another kind of wave is the Traube Hering wave. It is repeated more slowly than the respiratory wave, and is due to irregularity of excitation of the vasomotor center during a period within which it is being whipped, so to speak, to its utmost.

The Traube Hering curves are often present after large doses of morphia or accompanying hemorrhage.

The Effect of Digitalis and Strophanthus—Other agents affecting the vasomotor center are drugs. Digitalis and strophanthus both stimulate it.

Vasomotor Impulses of Spinal Origin—The preceding description demonstrates the important functions of the medullary vasomotor center, but are analogous functions possessed by the spinal cells from which the rami communicantes directly arise. We have

seen that a large fall in blood pressure follows a high division of the spinal cord. After, however, one or two hours the pressure will begin to rise. If, on the other hand, the spinal cord of the animal is destroyed, the blood pressure will sink to 0 and the animal will die.

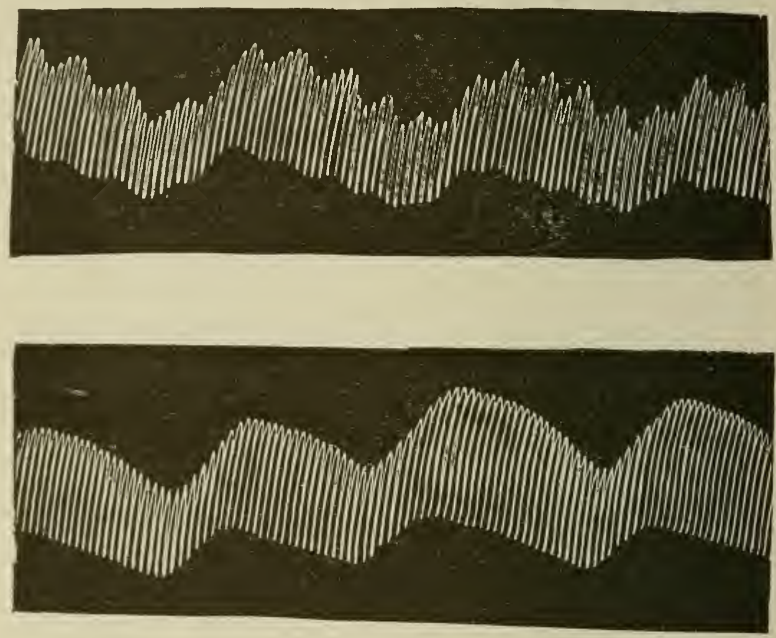


FIG. 89.—BLOOD-PRESSURE TRACINGS, SHOWING CARDIAC AND TRAUBE HERING CURVES.

In the upper tracing made during the continuation of artificial respiration, three curves are present: (1) Those due to the heart beat; (2) those due to respiration, termed respiratory curves; and (3) those due to irregular excitation of the vasomotor center and termed Traube Hering curves by some, and S. Mayer curves by others.

The lower curve is made from a curarized animal just after cessation of the artificial respiration. The cardiac and Traube Hering curves are alone present.

There must, therefore, exist in the spinal cord other vasomotor centers which participate to a certain degree in the maintenance of vascular tone and which are capable of replacing the medullary vasomotor center when the latter cannot functionate. There is no coordination between these centers and those controlling the heart.

The Susceptibility of the Spinal Centers to the Chemical Changes in the Blood—The spinal centers are susceptible to changes in the composition of the blood. In the rise of pressure which

follows asphyxia in the spinal animal the main factor is the deficiency in the lack of oxygen. A large excess, however, of carbon dioxid or the injection of lactic acid will produce a rise of blood pressure. (Fig. 90.) While 5 per cent. of carbon dioxid will stimulate the medullary vasomotor center, 25 per cent. of the

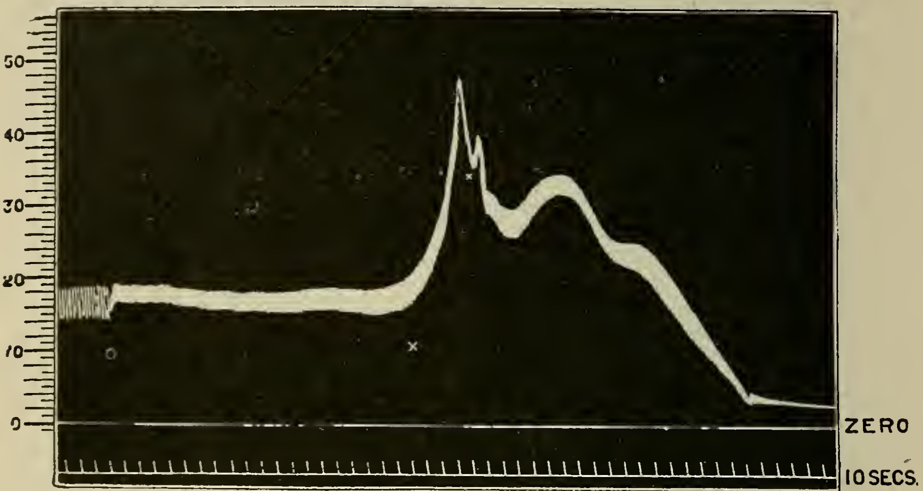


Fig. 90.—Blood-Pressure Tracing Taken by a Mercurial Manometer from Carotid Artery of a Dog, Three Hours After Section of the Cord, Just Below the Medulla Oblongata.

At *o* the artificial respiration was discontinued. A general spasm of the skeletal muscles occurred between *x* and *x*. The muscles then relaxed, and were flaccid during the rest of the rise of blood-pressure. (Starling.)

same gas is required to cause a rise of blood pressure in the spinal animal.

It takes two minutes before the rise of pressure which is due to the administration of nitrogen will come on in the spinal animal. In the same manner 2 cc. of a 1/20 normal solution of lactic acid will stimulate the vasomotor center in the medulla, while 5 cc. are necessary to produce a rise of pressure when the spinal centers alone are acted upon.

Local Constrictor Influences in the Vessel Walls—If the sciatic nerve of one leg is divided there will be an immediate dilatation of the vessels of this leg. But in a day or two this dilatation will pass off and the vessels remain in a state of average constriction. There is no proof that this regaining of tone by the vessels is due to a local nervous mechanism. It is far better to ascribe it to an

automatic myogenetic activity of the muscular fibers themselves which compose the wall of the vessels. The local changes in the caliber of the arteries can be determined by ascertaining the volumetric changes by a plethysmograph in conjunction with the arterial pressure. (Figs. 91, 92, 93 and 94.) In connection with local changes in the blood vessels it must never be forgotten that changes in the caliber of the blood vessels in one part of the body, and therefore in the amount of blood which this portion contains, is associated with reverse changes in another part of the body. This is due to the fact that when constriction or dilatation in one

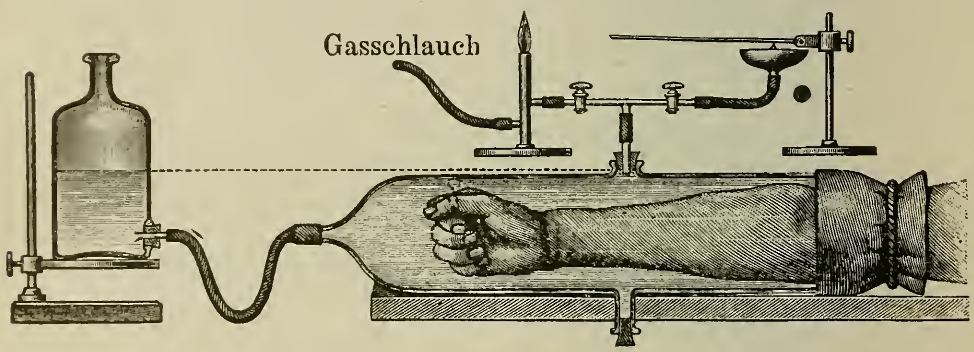


Fig. 91.—Plethysmographic Method of Taking the Changes in the Volume of a Limb and Two Methods of Transmission to the Recording Tambour.

set of vessels occurs there is more or less blood to fill the vessels elsewhere. (Fig. 95.) Such other vessels, therefore, dilate or contract from simply the increase or diminution of intravascular pressure.

Vasomotor Nerves Producing Dilatation—So far we have considered only the vasoconstrictor apparatus. It can be readily understood that it will be of great advantage to the body to possess a special mechanism for producing dilatation of the arteries, in other words, a double set of nerves equally efficient and opposing each other in their action. Only by the possession of such a mechanism can the organism respond rapidly and accurately to the needs of the body.

The chorda typmani and the nervi erigentes are examples of pure vasodilatatory nerves. (Fig. 97.) Stimulation of its peripheral end will increase the blood flow through the submaxillary gland five- or six-fold.

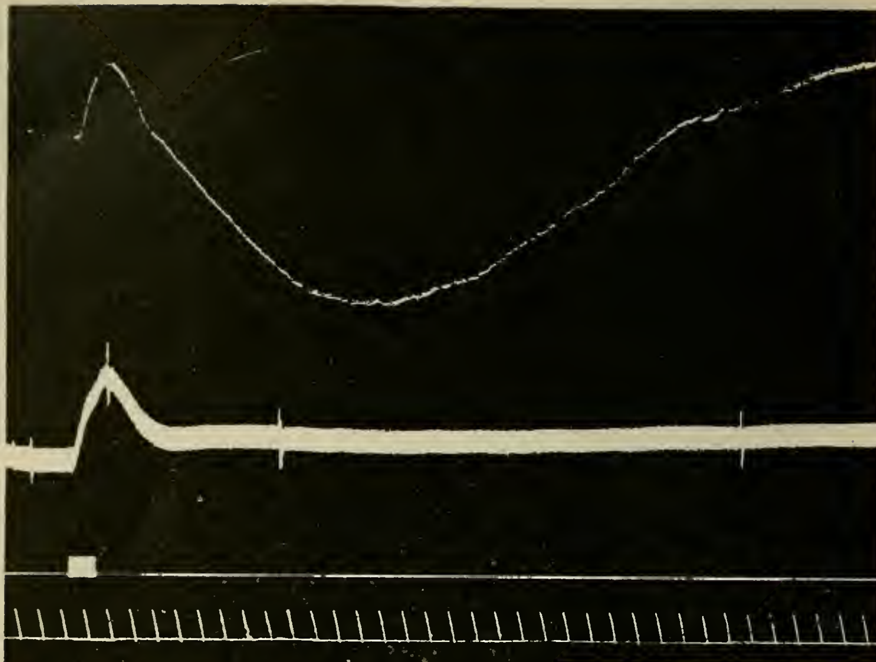


FIG. 92.—EFFECT OF SPLANCHNIC EXCITEMENT ON THE ENERVATED HIND LEG OF CAT.

Upper curve, volume of limb. Lower curve, blood pressure, zero being 45 mm. below excitation marker, which is the upper of the two bottom lines. Time in 10 sec. (N. M. Bayliss, "Reaction of Arterial Wall.")

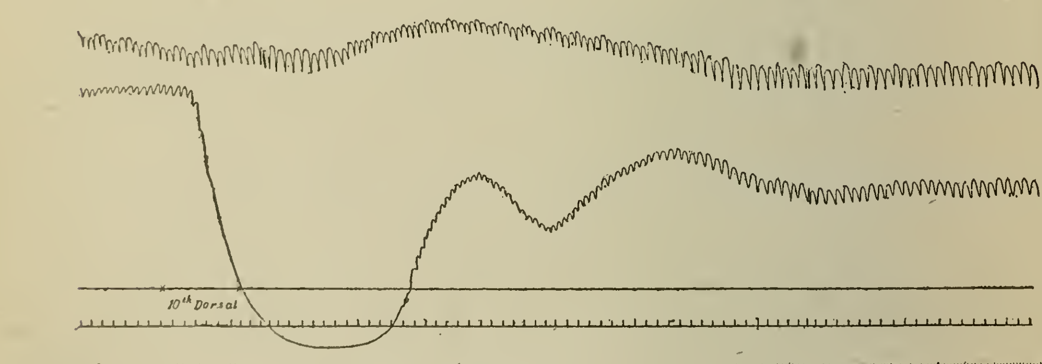


FIG. 93.—SIMULTANEOUS TRACINGS SHOWING THE RISE OF THE CAROTID BLOOD-PRESSURE AND THE FALL IN KIDNEY VOLUME DURING STIMULATION OF THE PERIPHERAL END OF THE DIVIDED TENTH DORSAL NERVE.

Time marking is in seconds and the period of stimulation occurred between the two x x marks. The fall in kidney volume is due to vasoconstriction in the splanchnic area, and the general rise of blood pressure depends upon the damming back of the blood upon the arterial side by the constricted arterioles in the splanchnic area.

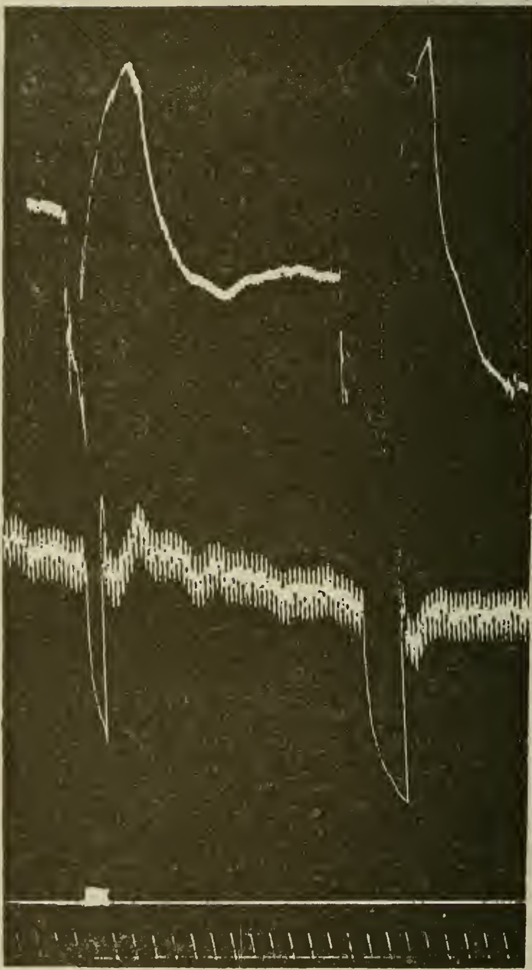


FIG. 94.—EFFECT OF COMPRESSION OF THE ABDOMINAL AORTA ON THE VOLUME OF THE HIND LIMB.

By the compression the blood pressure sinks to 0 and the volume of the hind leg diminishes greatly in size, but upon release of the pressure due to the temporary loss of tone the volume increases greatly at first and then, depending upon the stimulus of the increased intravascular tension to the muscle of the vessel wall, the arteries of the leg constrict, the experiment furnishing an illustration of the compensatory or accommodative power of the local mechanism.

Methods of Measuring Variations in the Circulation through a Portion of the Body—Various means have been adopted to estimate increase of blood flow through an organ.

1. Estimating the increase in redness of an organ.
2. The increase in the volume as measured by a plethysmograph or oncometer and controlled by synchronous blood pressure tracings.
3. In certain organs by their increase in temperature.
4. Increase in the velocity of the blood entering the organ.

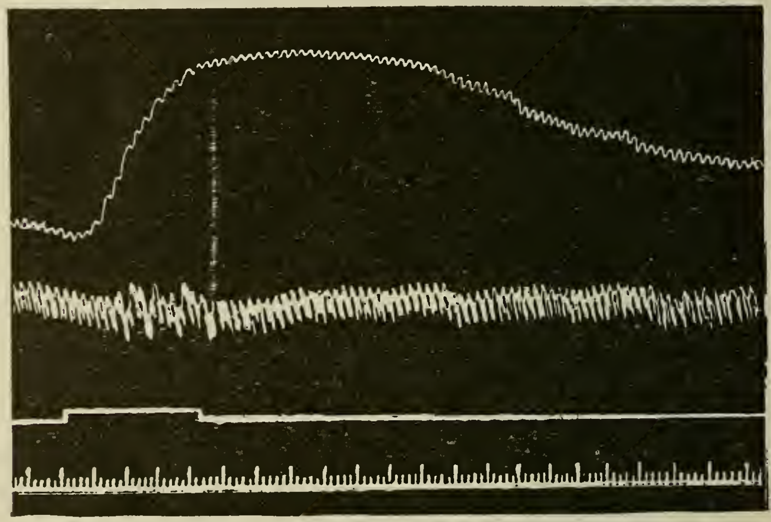


FIG. 95.—EXCITATION OF PERIPHERAL END OF 7TH L. POSTERIOR ROOT.

Uppermost curve, volume of limb; next below, blood pressure; the third line marks period of excitation, and the bottom line time in seconds. Blood-pressure zero 25 mm. below time marker. (N. M. Bayliss, "Vaso-Dilator Fibers.")

5. Increase of the venous outflow by a direct measurement.

The most valuable of these methods is the second. It is necessary, however, to measure synchronously the arterial blood pressure. A plethysmograph can be made of Stent's composition or vulcanite; it must be molded to the shape of the organ. It may be made in two halves or one-half large enough to accommodate the organ, and closed when the organ is within by a glass plate. Room must be left for the vessels and nerves passing to the organ. In Roy's oncometer the two halves are made of metal and hinged together. A bag which may be filled with warm oil surrounds the organ when inclosed in the instrument. Any increase in size of the organ will

displace the oil or air surrounding it. The displaced oil or air operates a recording tambour or float which is in series with the interior of the instrument. Such an oncometer is illustrated in the section on the kidney. Fig. 91 shows a plethysmograph adapted for taking volumetric changes in an extremity.

The Course of the Vasodilators—The course of the vasodilator nerves is quite different from that of the vasoconstrictors. Thus the chorda tympani is a cranial nerve issuing as the nerve of Wrisberg in connection with the seventh nerve. The dilators to the parotid gland issue with the ninth cranial nerve.

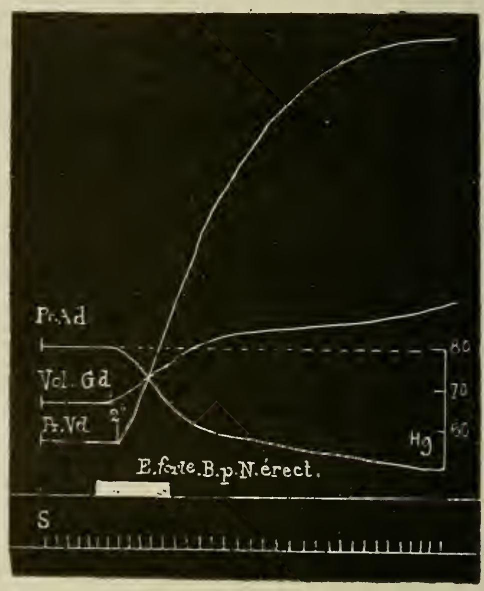


Fig. 96.—The Effect upon the Arterial and Venous Pressures of Excitation of a Vasodilator Nerve. A Dog with a Destroyed Bulb.

Pr. Ad., pressure in the peripheral end of the dorsal artery of the penis; Vol. Gd., volume of the organ; Pr. Vd., pressure in the peripheral end of the dorsal vein of the penis; E, period of excitation of one of the nervi erigentes; S, time in seconds. The size of the vessels entered were too small to transmit the arterial pulsations.

It is probable that most of the dilator nerves have their station peripherally embedded in the organ supplied by them. How many of them pass with the vasoconstrictors to the lower limb is not known. It is probable that the splanchnics convey vasodilator fibers to the vessels of the abdomen. If the constrictor fibers in them have been paralyzed by ergot, peripheral stimulation of the splanchnics will cause a fall of blood pressure.

Methods of Demonstrating the Existence of Vasodilator Nerves to the Lower Limbs—For the purpose of demonstrating the vasodilator fibers to the limbs two procedures are available.

The first method by division of the main nerve or nerves to the region in question and stimulation of these nerves peripherally after two or three days when the vasoconstrictor fibers have degenerated. The vasodilator fibers are still intact at this time. (Fig. 97.)

The second method of demonstrating the vasodilatory fibers is by stimulating the mixed nerve with weak induction shocks re-

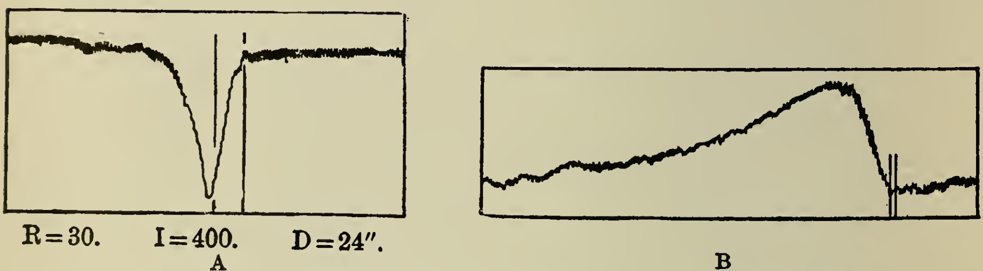


FIG. 97.—TRACINGS INDICATING PLETHYSMOGRAPHIC VARIATIONS OF THE VOLUME OF THE HIND LIMBS WHEN PERIPHERAL END OF THE DIVIDED SCIATIC NERVE WAS STIMULATED.

In A immediately after division, 30 times a second, with an intensity of 400 arbitrary units and a duration of each shock of 1/24 of a second, and in B four days after section. In A vasoconstriction was produced, and in B vasodilatation. (Burditch and Warren.)

peated at slow intervals only, one to four, or even 16, times per second. (Fig. 98.)

The Relation of the Vasodilators to the Postspinal Roots—These nerves pass from the spinal cord through the posterior spinal root instead of the anterior, as is the case with all other efferent nerves. They do not possess a connection in the posterior spinal ganglia. Stimulation of the posterior root both proximal and distal to the ganglion produces the same dilatation. (See Fig. 95.) Consequently the impulses in the posterior root of a spinal nerve pass along the vasodilator fibers in a direction opposite to the usual direction of impulses in the root. The vasodilator impulses are, therefore, spoken of as antidromic impulses. Vasodilatation produced by stimulating them is manifest upon a region far below the level at which the effect from stimulating the corresponding vasoconstrictor nerves results. Vasodilator reflexes may be evoked by

placing mustard or croton oil on the skin or conjunctiva. After such application the area treated becomes red and infected. Section of the posterior root proximately to the ganglion will not prevent this reflex dilatation, but sections distal to the ganglion will do so. It must, therefore, be concluded that the sensory nerves from the ganglion cell of the posterior spinal ganglion passing in a peripheral

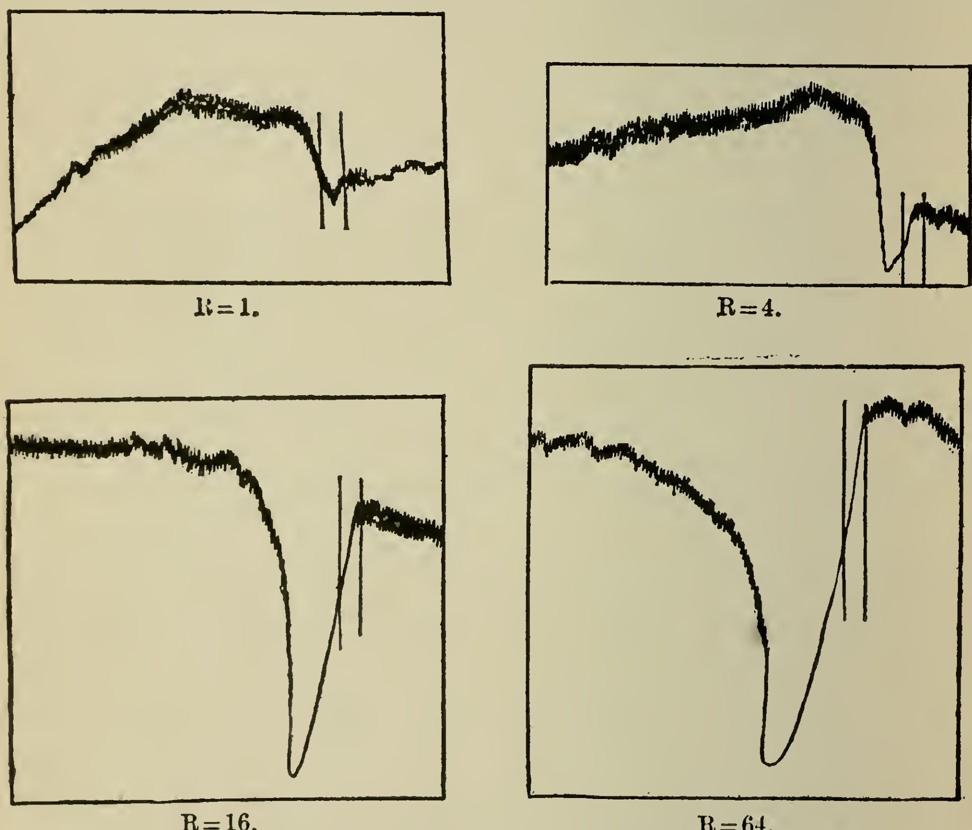


Fig. 98.—In These Four Experiments the Peripheral End of the Divided Sciatic Was Stimulated with a Constant Intensity and Duration, But with the Different Rates Indicated with a Slow Rate Vasodilatation Results and with Rapid Rate Vasoconstriction.

direction divide some fibers terminating as cutaneous sensory fibers in the skin, while others pass as vasodilator fibers to the walls of the blood vessels. We may term the vasoconstrictor nerves augmentor or motor and the dilator nerves to the periphery, dilator or inhibitory.

Afferent Paths for Vasodilatation—A similar classification may be made of the afferent nerves, though, of course, the tracts are more numerous and not so well defined. Those afferent impulses

which raise the blood pressure are called pressor impulses and those lowering the blood pressure are termed depressor impulses. Practically all sensory nerves conveying sensations of pain carry pressor impulses in the absence of consciousness.

The most important depressor nerves are the depressor nerve already described passing from the aorta, and the depressor fibers of the vagus nerve. Both terminate in the vasomotor center. Stimulation of the depressor nerve produces very prolonged effects.

From the brain also important depressor impulses arrive at the vasomotor center. Because this organ is responsible for the life

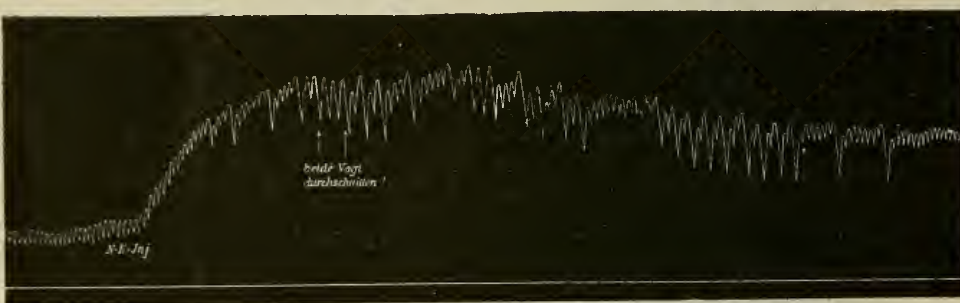


Fig. 99.—Illustrating the Large Increase of Blood Pressure and of the Excitability of the Vagus Center Due to the Intravascular Injection of Adrenalin.

Rabbit, artificial respiration. Injection of curare. Injection of adrenalin. When the blood pressure is highest the pulse showed the characters of a vagus pulse which became more marked after a division of both vagi nerves.

of the centers themselves, it demands to the last a good blood supply.

The Adrenalin Function—A powerful influence in producing vascular changes is adrenalin. This substance is secreted by the medulla of the suprarenal gland. The rapidity of the secretion is under the direct control of the abdominal splanchnic nerves. Injections of adrenalin produce a contraction of the heart, dilatation of the coronary vessels and universal vascular constriction. (Fig. 99.) Accumulations of carbon dioxid, as in asphyxia, lower the tonus of the heart and consequently favor dilatation. It also produces vasomotor constriction. This action is due to the effect of the carbon dioxid on the vasomotor centers. It is, however, associated with stimulation of the splanchnic nerves and, therefore, with the discharge of adrenalin. The action, however, of adrenalin on the heart is opposite to that of carbon dioxid,

and its discharge, therefore, into the circulation during asphyxia is an important conservative factor during period of excessive collection of carbon dioxid in the blood in preventing dilatation of the heart. It must not be forgotten that the constrictor effects of accumulations of carbon dioxid and lactic acid on the nerve centers are also opposed by the local dilator effects of these agents on the blood vessels, an effect which is very marked in the denervated limb.

QUESTIONS AND ANSWERS

Page 4

Q. What are the functions of the blood?

A. See text.

Q. Describe the red cells.

A. See text.

Page 6

Q. Describe the white cells.

A. See text.

Q. Describe the third corpuscles.

A. See text.

Page 10

Q. Define laking of the blood and mention some of the laking agents.

A. See text.

Q. What is hemoglobin and its important physiological property?

A. The real coloring substance of the red cells. Its power to form an easily disassociable compound with oxygen.

Q. In what two forms may oxygen be combined with hemoglobin?

A. As the easily disassociable form of oxyhemoglobin and the more stable form of methemoglobin.

Page 12

Q. What is carbon monoxid hemoglobin?

A. A combination of carbon monoxid and hemoglobin. The combination is a very stable one, depriving the hemoglobin of its power to unite with oxygen.

Page 14

Q. How may these various forms of hemoglobin be recognized?

A. By their characteristic spectra.

Page 18

Q. What tissues form the red blood cells?

A. In the embryo the mesenchymic cells, which form the earliest vessels; later in the fetus, in the liver, spleen and bone marrow, and finally after birth the bone marrow.

Page 22

Q. What are the varieties of the white cells?

A. See text.

Page 24

Q. Where are the white cells formed?

A. The lymphocytes in the lymph glands, the neutrophiles and eosinophiles in the bone marrow.

Page 30

Q. What are the blood plaques?

A. Small globular structures about one-third the size of a blood cell,

with apparent organization containing a central more highly refractile and darker staining portion and a surrounding protoplasmic-like body, presenting star-like angles at its periphery, from which fibers may radiate. It is probable that they do not exist in the circulating blood, but are proteins of the blood precipitated by shedding which contribute toward the clotting process.

Page 34

Q. What methods or agents will prevent blood from clotting?

A. See text.

Q. What is the mechanism of clotting?

A. The formation of a mesh-work of fibrin by a combination of thrombin with fibrinogen, the thrombin itself being first formed from prothrombin in the presence of lime salts. In the circulating blood prothrombin does not form thrombin, because of the presence of sufficient antithrombin. In shed blood a substance called by Howell a thromboplastic substance, and by others thrombokinase, is formed which either (Howell view) neutralizes antithrombin, or (other views) forms in the presence of lime salts thrombin by reacting with prothrombin or thrombogen.

Page 44

Q. How do the various anti-coagulants act?

A. See text.

Page 48

Q. What is the reaction of blood?

A. Very slightly alkaline to litmus, or as estimated by the electrical method.

Page 50

Q. Give the composition of blood.

A. Fibrin { Fibrinogen
Thrombin

Serum { Serum albumen
Serum globulins

Red and white cells

Total proteins about 8 parts.

Salts, 1 part; of these Sodium chlorid 60%
Sodium carbonate 30%
Potassium, Calcium, traces
Phosphates 0.512

Page 54

Q. What are the four kinds of vessels transporting the blood, and how do they differ, and what is their function?

A. Arteries, large vessels with thick muscular and relatively large amounts of elastic tissue, the largest of these vessels having relatively less muscle and capable of changing their diameter but little. The arterioles, very small vessels, the media of which is pure muscle. They are capable of large changes in their diameter. The capillaries, about the same diameter as the arterioles, but far more numerous, so that their total sectional area is greater. They possess very thin walls, containing no muscle, their walls being merely a single layer of endothelial cells. The veins, varying in size from minute venules to

LECTURE NOTES ON PHYSIOLOGY

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DEVELOPMENT

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DEVELOPMENT

The Function of the Development of Species—A study of the functions of the various organs and tissues of the body, and a comparison of these functions with the physiological activities of the simplest forms of life, discloses the fact that the most striking difference between the simple forms of life and the complex mammalian organism is the development of a higher perfection of function in the mammal, by the setting aside of whole groups of cells for a single function. The mammal, however, starts its existence as a single cell. This cell, therefore, must contain within itself not only all the gross physiological forces of which the subsequently fully developed organism is capable, but power of reproducing from itself in an orderly manner the fully developed organism itself. The forces which set aside each cell descendent from the primary genital cell from which a complex organism springs, which determine the place and exact degree of variation in each of these descendent cells, belongs to the function of growth.

Growth—Growth is restricted in the popular conception to an increase in size, but it is impossible to distinguish between those forces which produce a steady increase in size of a cell and those forces responsible for the interruption of this process at a proper time by a division of the cell into two cells. Growth, therefore, includes reproduction. It is a process which determines the exactness of the structure, number, position and degree of variation of the successive descendents of the primary cell from which any animal has developed.

The Two Important Factors of Development—Two factors associated with growth are responsible for the continuation of life by the process of growth, a continuation meaning not only its preservation but its continuous improvement. One of these factors is the faithfulness with which any consecutive series of cell divisions, representing the development of a single individual, reproduces the past series of cell divisions, representing the development of that individual's progenitors. The other factor is the

possibility of continued variation in this same faithfulness in only the direction leading to improvement of the species in question.

The Causes for Variation—There are two important causes for variation. One is the adaptation to a changing environment, and the second is the variation induced by the sexual method of reproduction. The response of the process of growth to these two causes of variation has made possible the existence of forms of life possessing the greatest perfection in the specialization of function by the individual tissues. Nevertheless, the exactness with which any series of cell divisions, representing the growth of any animal, repeats itself is very great, so great that the offspring not only closely resembles its progenitors, but in the process of its development repeats all the variations which have been responsible for its differing from the simple form of life which originally, at some remote time, preceded it on this earth.

The Primary Stimulus to Growth—Each human being starts its existence as a single cell, the fertilized ovum. The impetus to growth of this single cell results from the union of the nucleus of the spermatozoön with the nucleus of the ovum.

EARLY PROCESSES OF DEVELOPMENT

The Ovary—The ovum is produced by the ovary. Each human female possesses two of these organs. They are situated in the pelvis, and suspended from the posterior surface of the broad ligaments, those ligaments which furnish the lateral support to the uterus.

The infantile ovary is laden with from 10,000 to 100,000 ova, many of which disappear during the subsequent life of the individual by absorption. The ova are formed from the germinal epithelium, which covers the surface of the ovary. This epithelium forms tubular invaginations from the surface. The deepest portions of such invaginations become cut off from the surface, and alone remain as small isolated nests of cells, one of which becomes an ovum. Such an isolated nest is known as the Graafian follicle. (Figs. 1 and 2.)

Ovulation—At puberty and for approximately the next thirty years one Graafian follicle after another enlarges and bursts. The

enlargement of the follicle is due to the enlargement of the ovum, by the proliferation of the cells lining the follicle and the collection of a fluid—the liquor folliculi—within the cavity of the follicle.

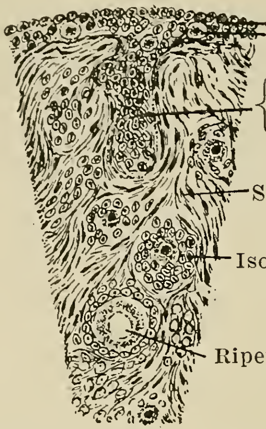

FIG. 1.—DIAGRAMMATIC SECTION OF THE OVARY OF A FIFTH MONTH FETUS, SHOWING NESTS OF GERMINAL EPITHELIUM AND UNRIPE GRAAFIAN FOLLICLE.

Finally the follicle becomes so large that it bursts, and the ovum, surrounded by a collection of the cells of the follicle, which remain attached to it and constitute the discus proligerus, is dis-

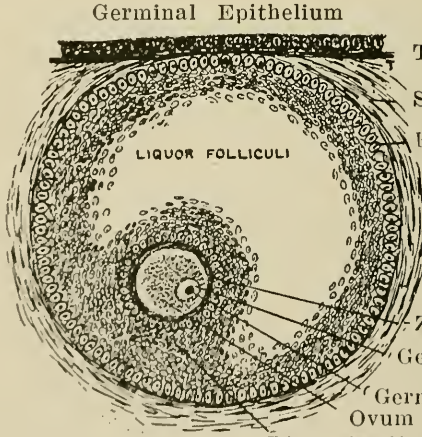

FIG. 2.—RIPE GRAAFIAN FOLLICLE AT PUBERTY.

charged upon the surface of the ovary. By the ciliary activity of the epithelial cells lining the fimbria of the Fallopian tube (Fig. 3), the ovary is now carried into the Fallopian tube, and by the

same ciliary action, along the tube to the uterus. In the absence of the spermatozoa within the tube, the ovum passes into the uterus and perishes, or is discharged with the menstrual fluid.

The cavity left within the ovary after the rupture of the Graafian follicle fills with blood clot and a cellular tissue, due to the proliferation of the cells lining the cavity—the theca interna. These cells develop a yellow pigment called lutein within them. The whole mass shrinks in size and disappears during the next month. It is called the corpus luteum menstrualis. If on the other hand the ovum is fertilized, instead of the remains of the ruptured

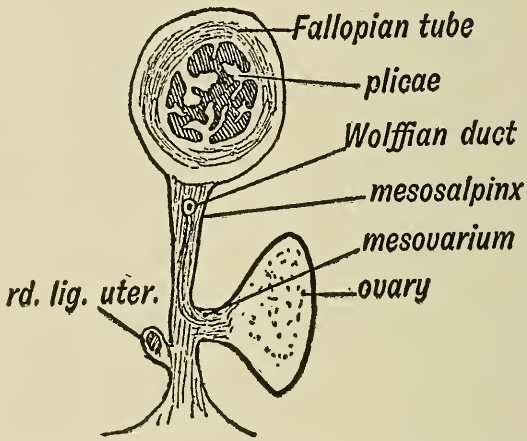

FIG. 3.—DIAGRAMMATIC SECTION OF THE BROAD LIGAMENT AND FALLOPIAN TUBE.

Graafian follicle shrinking, it increases in size until it forms a glandular body as large as a pigeon's egg. It is called the corpus luteum gestionis.

Fertilization—Fertilization of the ovum is accomplished by the penetration of it by the spermatozoön. The spermatozoa are formed in the testes of the male. The testes are the generative glands of the male. They are two in number, and are situated in the scrotum. They are compound, tubular glands. Each tubule is lined with two kinds of cells: the spermatogonia and the cells of Sertoli. The cells of Sertoli serve to nourish the spermatogonia, and correspond to the cells lining the Graafian follicle which surround the ovum. (Fig. 4.)

By division each spermatogone produces a primary spermatocyte. A primary spermatocyte by division produces two

secondary spermatocytes, each of which divides and produces two spermatozoa. These last soon after formation become free. When fully developed a spermatozoön possesses a pear-shaped head, a neck and long tail. The pear-shaped head is practically all chromatin, and its chromatic substance is composed of just one-half the total number of chromosomes characteristic of the species, or belonging to the spermatogones. The reduction of the number of chromosomes takes place in the formation of the secondary spermatocytes from the primary. By this reduction of the total number of chromosomes, the spermatozoön is prepared to add to the ovum one-half the number of chromosomes characteristic of the species, which with the one-half number of chromosomes remain-

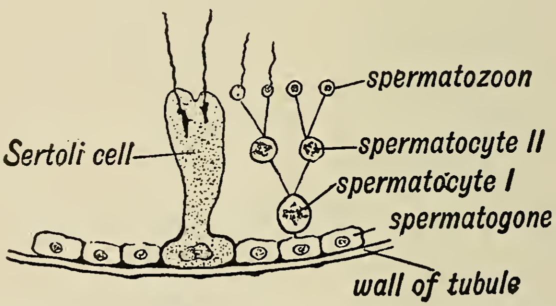

Fig. 4.—Diagram Showing the Origin of Spermatozoa from the Living Cells (Spermatogonia) of the Tubules of the Testicle.

ing in the ovum prepared by a similar process for fertilization in the Fallopian tube, makes in the united nuclei of the spermatozoön and the ovum exactly the right number of chromosomes for the species.

When the ovum enters the Fallopian tube it measures 250 micromillimeters in diameter. After entering the tube, or immediately before, it divides twice and each time into two very unequal portions. Each portion, however, contains exactly the same number of chromosomes. During the second division, however, only one-half the number of chromosomes are formed. It is thus that the total number of chromosomes in the ovum becomes reduced to one-half the normal number for the species.

The ovum is now prepared for fertilization. If coitus has taken place at a time sufficiently close to ovulation, and ovulation may occur quite independently of menstruation, the spermatozoa will have forced their way by means of the flagella-like movement of

their tails up through the cavity of the uterus and into the Fallopian tubes, and will there meet the ovum.

Live spermatozoa have been found within the Fallopian tubes nine days after coitus. The ovum then becomes surrounded by the spermatozoa, but only one spermatozoön is permitted to enter the ovum. The successful spermatozoön forces its head through the zona radiata or cell wall of the ovum and loses its tail. Its head now inside enlarges and approaches the nucleus of the ovum. The two unite, their chromatic substance mixing, and the ovum is once more furnished with the full quota of chromosomes characteristic of the species, but half of its chromatin has now come from the male sex. The ovum is now ready to start upon that growth, which results in the full termed baby within 280 days.

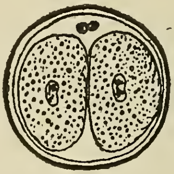

Fig. 5.—The Ovum After the First Division.

The Early Stages of the Development of the Ovum—The first stages of cell divisions of the fertilized ovum probably occur within the Fallopian tubes. By rapid cell division of the ovum and its descendent cells there is first formed a rounded mass of cells called the morula or blastula (Figs. 5, 6 and 7) ; it is probably in this stage that the developing ovum enters the cavity of the uterus, and becomes implanted in one of the pits of the uterine membrane, being then about 2 millimeters in diameter. The cells of the blastocyst now arrange themselves into two sets (Fig. 8), an outer enveloping layer called the trophoblast, and an inner mass of cells which forms a thin lining within the trophoblast.

The Chorion and Its Development—The trophoblast rapidly proliferates, separating into a deeper basal layer and a superficial syncytial layer (cells which have undergone multiplication of their nuclei without separation of their cell bodies). The syncytium forms projections which burrow into the cells of the uterine mucous membrane, anchoring in this manner the ovum to the uterine cavity, and obtaining nourishment from the uterine mucous mem-

brane, probably in large part by an absorption of the uterine cells themselves.

The syncytial processes develop to a far greater degree on that aspect of the ovum which is in relation with the embryogenetic pole. Here they form rapidly growing projections, which eat their way into the uterine mucous membrane and, with a true phagocytic power, absorb the tissue forming the walls of the uterine vessels, thus allowing the maternal blood to escape into spaces

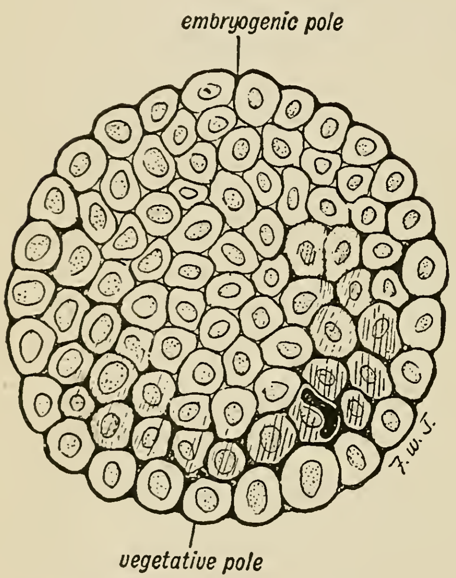

FIG. 6.—STAGE I. THE BLASTULA.

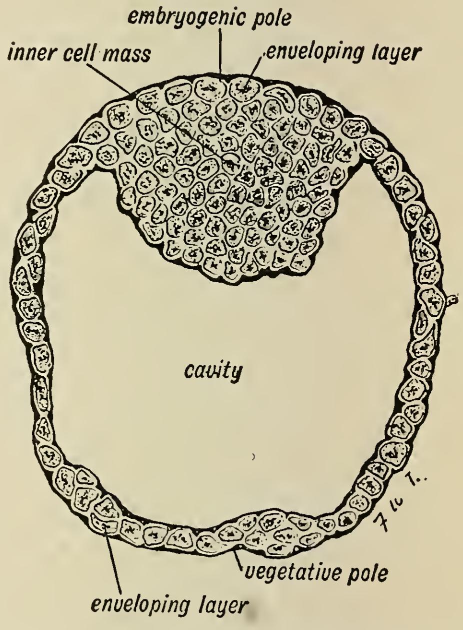

FIG. 7.—STAGE II. THE BLASTOCYST. (After Van Beneden.)

enclosed by syncytial cells and ultimately resulting from the vacuolization of the syncytial processes. Into these spaces there later grow diverticulæ or processes composed of both the epiblastic and mesoblastic layers of the trophoblast. The trophoblast becomes transformed into a sac covered with these processes bathed in the maternal blood and is now called the chorion.

With the successful lodgment of the ovum upon the uterine mucous membrane the uterine membrane hypertrophies in a manner to surround the ovum. To the hypertrophied uterine membrane the name of desidua is applied: the desidua serotina—that portion of the uterine mucous membrane to which the ovum is attached; the desidua reflexa—that portion of the hypertrophied

uterine membrane heaped up around the ovum; and desidua vera —that portion lining the rest of the cavity of the uterus.

The Development of the Three Germinal Layers—Meanwhile the thickened mass of cells within the trophoblast, at the so-called embryonic pole of the ovum, separate into two sets of cells. The innermost layer of cells is called the hypoblast. They spread out in a single layer around the whole internal surface of the tropho-

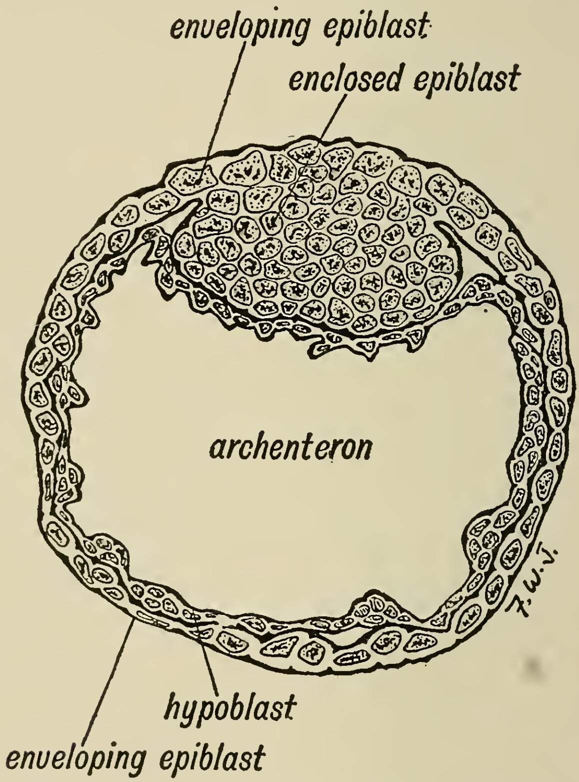

FIG. 8.—STAGE III. BILAMINAR BLASTOCYST. (After Van Beneden.)

blast. They partially surround, at the embryonic pole, an outer set of cells forming the main body of the mass of cells at the embryonic pole and known as ectoblast or epiblast. These epiblastic cells may be called the enveloped or enclosed epiblast, to distinguish them from the inner layer of trophoblast cells, which are designated the enveloping epiblast. (Fig. 15.)

The Cœlom and Amnion—In the human embryo a wide cleft or cavity, the cavity of the cœlom, develops between the hypoblast and the enveloping epiblast, and the cavity becomes lined with a single layer of a new variety of cells, which thus forms a

double layer: that portion of the layer in contact with the hypoblast and that portion in contact with the enveloping epiblast. These new cells form the mesoblast. (Fig. 8.) The appearance of this cleft causes the original cavity of the blastocyst inclosed by the hypoblast to become relatively much smaller. It is now called the cavity of the archenteron, and comes to lie in close apposition to the enclosed epiblast at the embryonic pole of the cell. At the same time this portion of the epiblast incloses a new cavity, the amniotic cavity. (Fig. 9.)

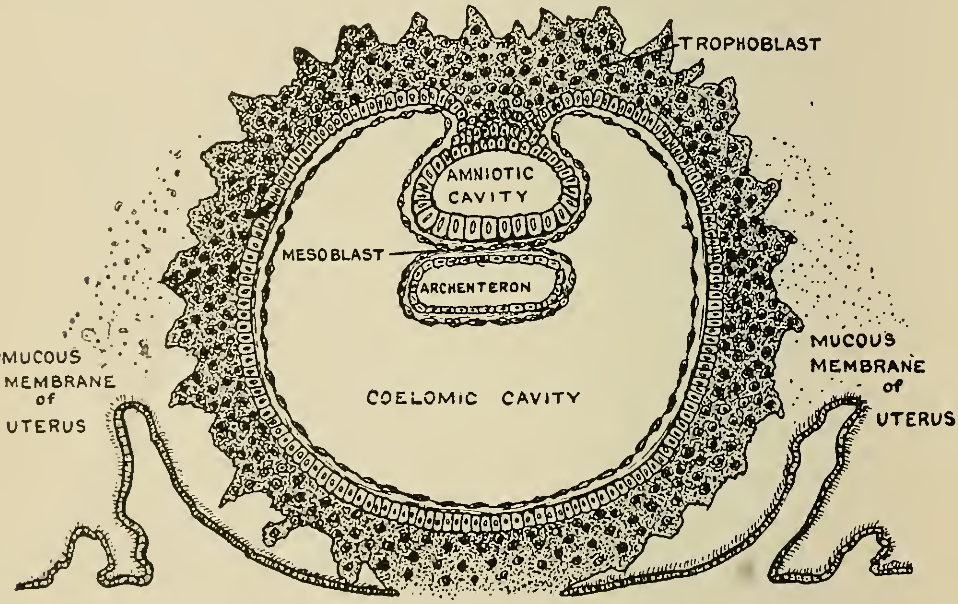

Fig. 9.—Showing the Origin of the Primitive Cœlom, the Mesoblast and the Cavity of the Amnion During the Development of the Human Ovum. (After T. H. Bryce.)

The Embryonic Area—At this stage the cavity of the archenteron is relatively very small. It lies in close apposition to the epiblast of the amniotic cavity. The epiblastic cells enclosing that portion of amniotic cavity contiguous to the archenteron now separate into two layers, a flatter layer of cells forming the dome of the amniotic cavity, and a columnar layer of cells separating the amniotic cavity from the cavity of the archenteron. (Fig. 10.) Projecting into the angle between them and the archenteron are the mesoblastic cells lining the cœlomic cavity. It is from the portion of the epiblast, mesoblast and hypoblast in contact at this place that all the tissues and organs of the fetus de-

velop. In other words, the layer of columnar cells between the archenteron and the amniotic cavity form all the epithelial covering of the body, and all the cells of the nervous system. All these stages are completed in about 12 to 14 days.

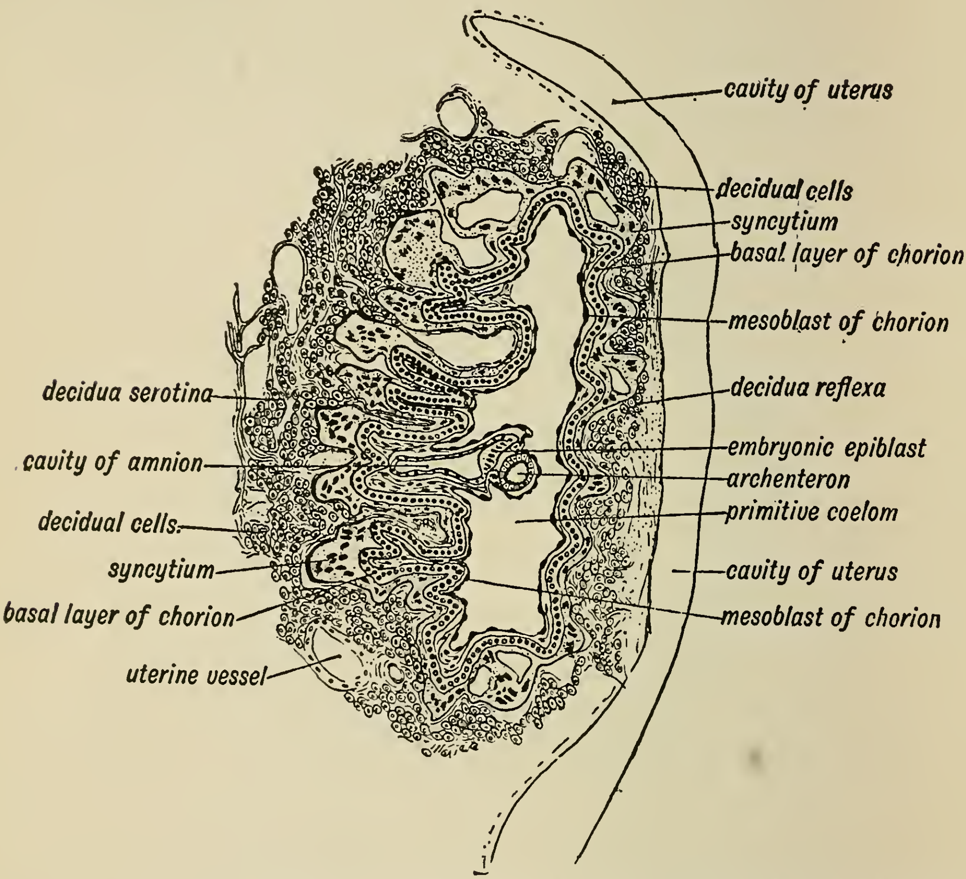

Fig. 10.—Stage IV. Section Through the Ovum Embedded in the Wall of the Uterus. (Modified by F. W. Jones from figures given by Peters and Selenka.)

The Development of the Primitive Alimentary Canal—The archenteron now divides into an extra embryonic portion, becoming the yolk sac, and the intra embryonic portion, which becomes the intestinal canal. The intra embryonic portion becomes intra embryonic as an anterior and a posterior diverticulum. From the anterior diverticulum which grows into the head fold is formed the foregut.

The posterior diverticulum grows into the caudal extremity of the embryo and a communication with the cavity of the amnion

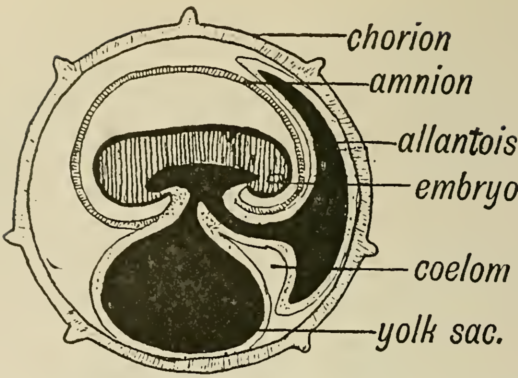

Fig. 11.—The Primitive Form of the Allantois. (After Turner.)

forms through the epiblast. This communication is called the neurenteric canal, and connects the cavity of the amnion and the cavity of the archenteron.

The Allantois—From the posterior diverticulum of the intra

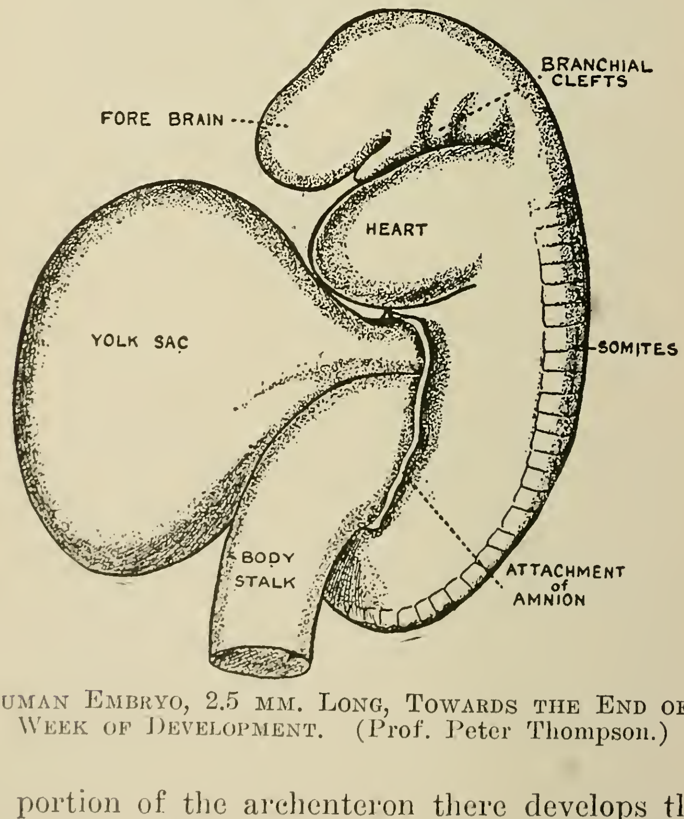

Fig. 12.—Human Embryo, 2.5 mm. Long, Towards the End of the Third Week of Development. (Prof. Peter Thompson.)

embryonic portion of the archenteron there develops the hindgut and the allantois. (Fig. 11.) The allantois grows out as a sac projecting at first into the cœlomic cavity, and finally as it en-

larges, inserting itself between the yolk sac and the mesoblastic cells lining the interior of the trophoblast. Its layers, in contact with the trophoblast, spread around the whole of the interior of the trophoblast and fuse with it, and participate in the formation of the chorionic processes, which float in the maternal blood channels.

The portion of the allantois connecting the hindgut with the chorion, what may be termed the neck of the allantois, becomes contracted into a cylindrical stalk-like structure, lying at the side of the yolk sac and surrounded by the fluid of the cœlomic cavity. It is termed the body stalk (Fig. 12), and ultimately incloses the atrophied yolk sac, becoming the umbilical cord.

THE CONTINUED PROCESS OF DEVELOPMENT

The Umbilical Cord, Chorion, Placenta—By the continued enlargement of the cavity of the amnion the wall of the amnion comes into contact with the allantois, the latter coming to occupy a narrow cleft between the amnion internal to it and the trophoblast external to it, and with which it forms the chorion. These three structures fuse and participate in the formation of the umbilical cord and chorion. (Fig. 13.) In the early periods of its development the allantois probably served as a receptaculum for the secretions of the kidney. It becomes, however, soon vascularized by the vessels from the yolk sac, and after this process serves to transmit the fetal blood to the uterine sinuses.

From the 14th to 21st days the various tissues of the embryo become rapidly differentiated. These are all formed from the portion of the epiblast and hypoblast, situated between the cavities of the archenteron and the amnion, and from the mesoblastic cells, which push their way in from the periphery of the region where the epiblast and hypoblast are contiguous.

The Formation of the Neural Canal—A groove forms in the epiblast (Figs. 14, 15, 16 and 17), deepening into it from the amniotic surface of the epiblast. By the deepening of this groove and its subsequent transformation into a canal the central canal of the cerebrospinal nervous system is formed. From the cells lining this canal are formed all the nerve cells and neuroglia cells of the nervous system.

By the growth outward from certain of these nerve cells to the periphery of the body all the motor nerves are formed. The sensory nerves, on the other hand, grow from groups of epiblastic cells, folded in at the side of the central neural groove. From

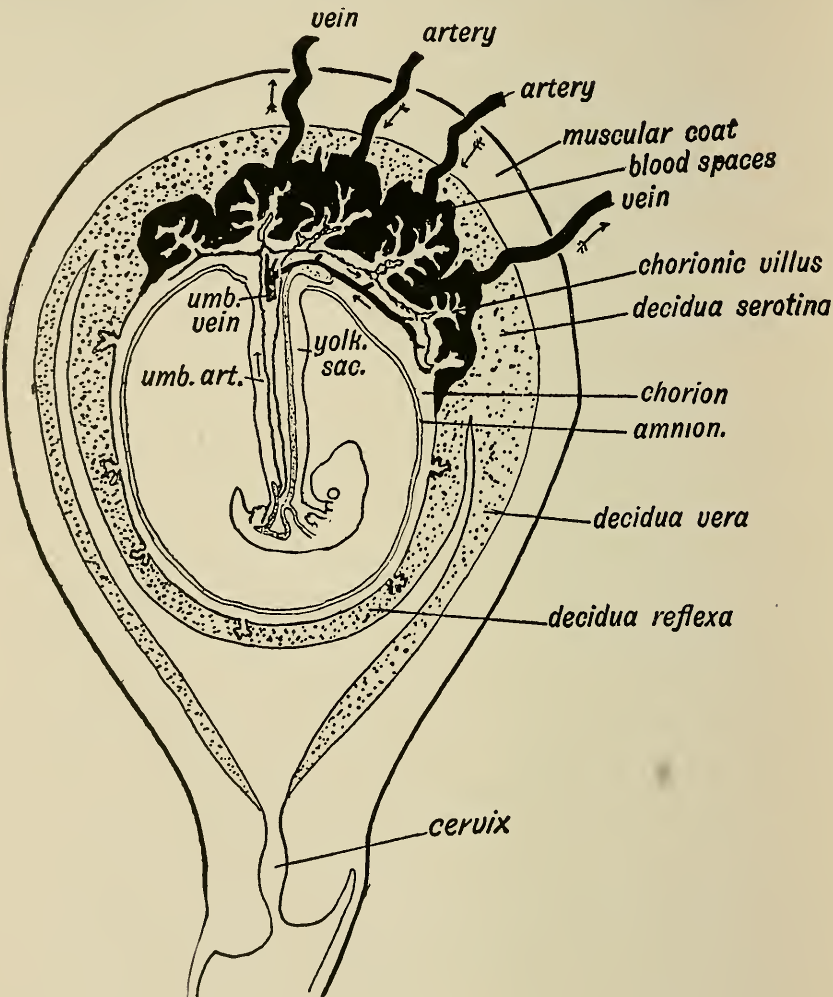

Fig. 13.—Showing the Arrangement of the Amnion, Chorion and Decidua in the Third Month and the Formation of the Placenta.

these cells processes which become nerves grow out from both ends of the cells. One process grows externally and connects with a sentient cell in the periphery of the body. The other process grows into the central nervous system. These cells are therefore bipolar, and their processes constitute the sensory paths to the central nervous system.

The Notochord—The formation of the alimentary canal from

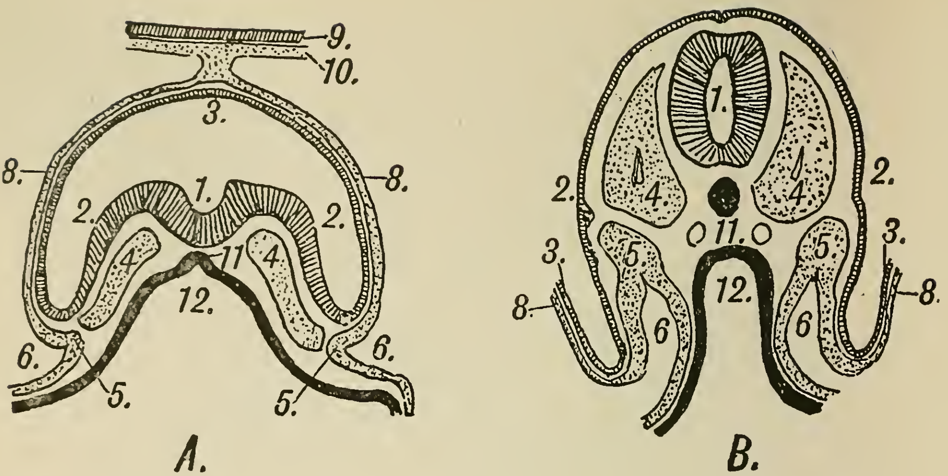

FIG. 14.—SCHEMATIC TRANSVERSE SECTIONS OF TWO HUMAN EMBRYOS.

A, About 12 days. (After Kiebel.) *B*, About 15 days. (After Kollmann.) The numbers are placed on corresponding points: Epiblast, shaded; hypoblast, black; mesoblast, stippled.

1. Neural grove and canal. 2. Epiblast of embryo. 3. Epiblast lining amnion. Only the attachment of the amnion is represented in *B*. 4. Paraxial mesoblast. 5. Intermediate cell mass. 6. Cœlom, bounded by the somatopleure externally and splanchnopleure internally. 8. Mesoblast on amnion. 9, 10. Chorion. 11. Notochord. 12. Archenteron.

the archenteron and its division at first into foregut and hindgut, has already been explained. However, in addition to the alimentary canal, there becomes also separated from the median wall of the archenteron a strip of cells which plays the part of a support to the early embryo. This column of cells is known as the

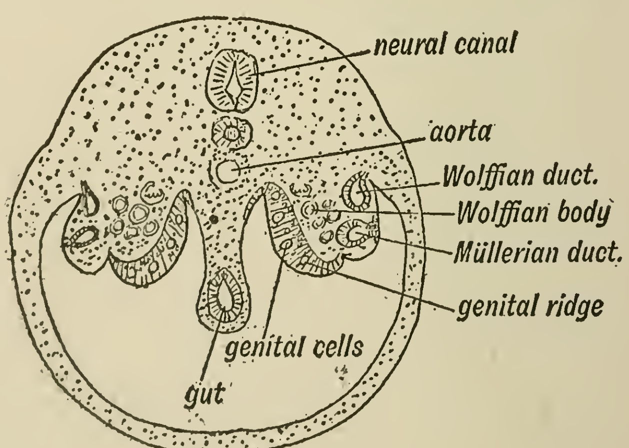

FIG. 15.—DIAGRAMMATIC SECTION OF THE ABDOMINAL REGION OF THE CŒLOM, SHOWING THE POSITION OF THE GENITAL RIDGES FROM WHICH THE OVARY OR TESTICLE IS FORMED.

notochord. (Figs. 14 and 15.) It disappears later, beginning to do so about the second month, and becomes replaced by the vertebral column, the bodies of which and the parachordal cartilages grow in around it and obliterate it entirely, except in the center of each intervertebral disc, where it swells out and forms a considerable part of the central mucoid core. The anterior part of the notochord has been found on the dorsal wall of the pharynx in the human embryo.

The Development of the Mesoblastic Structures—As has been said the two layers of the mesoblast, the splanchnopleure, that layer

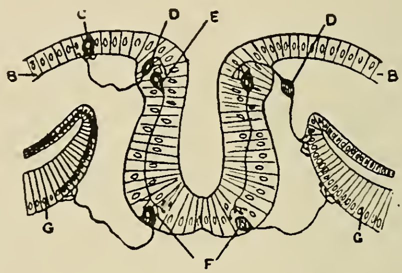

Fig. 16.—Diagram to Show How the Ectodermal Cells of the Medullary Plates Are Differentiated into Nerve Cells or Neuroblasts and Supporting Cells or Spongioblasts. (After Prenant.)

The central canal is being enclosed by upgrowth of the medullary plates. *B, B,* ectoderm; *C,* sensory cell in ectoderm; *D, D,* cells which become enclosed in posterior root ganglion; *E, E,* nerve cells which connect the sensory and motor cells; *F, F,* motor cells in anterior horn; *G, G,* muscle plates.

lining the archenteron, and the somatopleure, that layer lining the outer wall of the cœlom, grow in between the epiblast of the floor of the primary amniotic cavity and the contiguous wall or roof of the archenteron.

From these cells all the mesoblastic tissues of the body, the muscles, bones and connective tissue, are formed. The mesoblast coming from them shows a division into four portions:

1. The paraxial mesoblast (Fig. 14), from which the voluntary muscles, bones and connective tissue structures arise.

2. The intermediate cell mass, which forms the basis of the renal and genital organs.

3. Somatic mesoblast, from which the parietal layers of the pericardium pleura and peritoneum are formed.

4. Splanchnopleure, from which the visceral layers of pericardium pleura and peritoneum are formed.

The Muscular System—During the third week the paraxial mesoblast separates into 33 segments. These segments are called somites. From each somite there develops subsequently a united system of bones, muscles, nerves and vessels, so that all these structures which in the completely developed body possess a definite relation with each other, a relation in part anatomical and in part functional, are derived from one somite. An illustration would

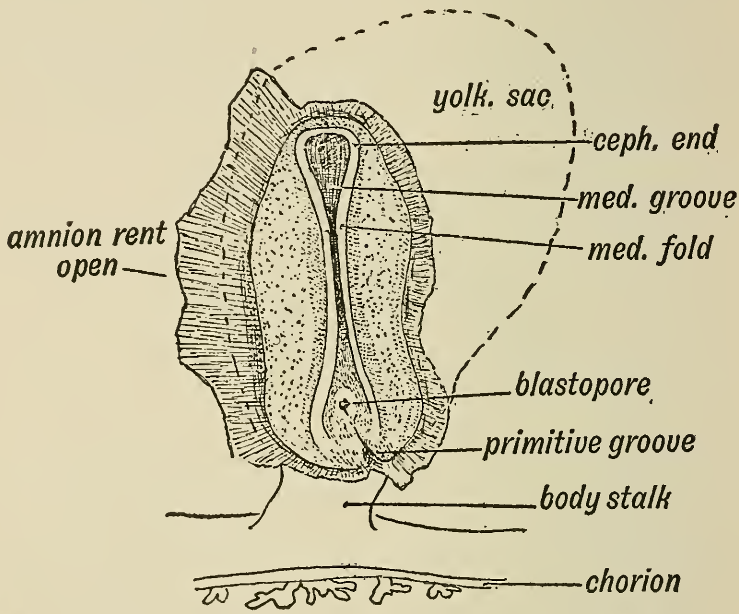

FIG. 17.—MEDULLARY FOLDS UNITING TO FORM THE NEURAL TUBE IN A HUMAN EMBRYO OF ABOUT FOURTEEN DAYS. (After Graf Spee.)

be furnished by the vessels and nerves and muscles and bones of an intercostal space.

The process of segmentation begins at the beginning of the third week in the cervical region. By the end of the week 30 segments (Fig. 12), which go to form the cervical, dorsal and lumbar and sacral regions, are marked off. In the fourth week three occipital segments appear, and in the fifth week eight or ten coccygeal segments are developed. The process of segmentation does not involve the epiblast or hypoblast, but only separates the paraxial mesoblast.

The Urogenital System—The anlage or basis of the urogenital system appears at a very early period. Toward the end of the third week the cells of the intermediate cell mass form themselves

into a ridge which projects into the cœlom. (Fig. 15.) The cells covering these ridges, indistinguishable from mesothelial cells, form themselves into columnar cells. These ridges are known as genital ridges. They form the basis of the genito-urinary system. More accurate observations show that at a very early stage, even in the blastula stage, cells migrate toward the genital ridges from which the epithelium of the genito-urinary system is derived; so that the epithelium of this system is probably not derived from the cells on the genital ridges which have undergone advanced mesothelial differentiations but from cells preserving their un-

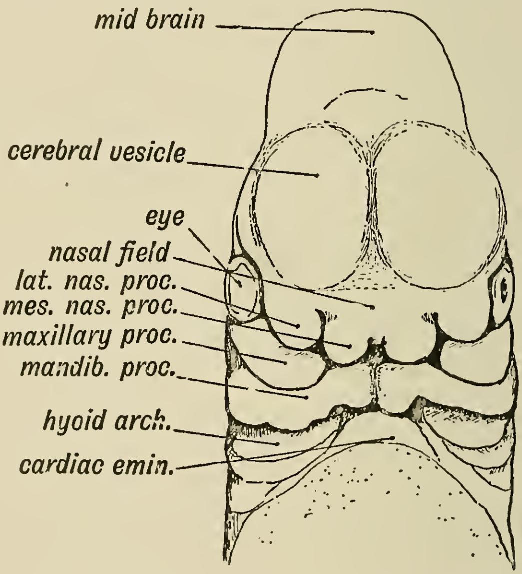

Fig. 18.—Showing the Formation of the Face by the Nasal, Maxillary and Mandibular Processes in an Embryo of the Fourth Week. (After His.)

differentiated character at the site of this mesothelial tissue. Thus it comes about that during the first three weeks the bases of all the organs in the body have been set apart.

The subsequent development of the body depends almost entirely upon a process of budding from the various cell deposits which have been set apart during the first three weeks of development in the manner described.

The Development of the Face—The manner of the development of the face is of much importance to the oral surgeon for a proper understanding of the various congenital deformities occurring in the face, nose and mouth.

The nasal and oral cavity become closed in and the face formed by the forward growth and union anteriorly of five processes, which begin to grow forward from the base of the primitive cerebral capsule about the end of the third week.

The names of these processes and the parts to which they give rise (Figs. 18 and 19) are as follows:

1. From above down, the nasal or frontonasal process. This process is median, but possesses an anterior bifid extremity. It

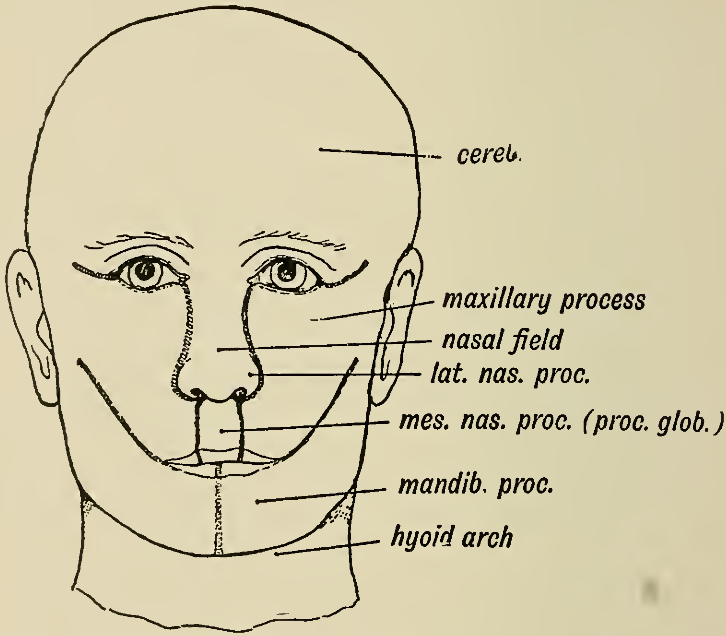

Fig. 19.—Showing the Parts of the Face Formed from the Nasal, Maxillary and Mandibular Processes.

forms in the adult the brow and bridge of nose and septum and middle portion of lip.

2. The lateral nasal processes. These curve forward above the eye to form in the adult the alæ nasi, the roof of the nose, the cribriform plate, the lateral mass of the ethmoid and the inferior turbinate.

3. The maxillary processes. These grow forward beneath the eye, and form the superior maxillæ, including their frontal processes, and later the orbital, palatine, and alveolar processes, the outer ⅔ of the upper lip and the cheek between the eye and the lip.

When the maxillary processes fail to unite with the mesial

nasal process, hare lip results, and when its palatine process fails to join the mesial nasal process, cleft palate represents the deformity.

4. The mandibular processes. From these are formed the inferior maxillæ and the overlying soft parts. When the two mandibular processes fail to unite at the symphysis the rare deformity of mesial cleft in the lower lip results.

5. The hyoid processes or hyoid arch.

The Development of the Neck—There are many features in which the human embryo during the early stages of its development resembles a fish.

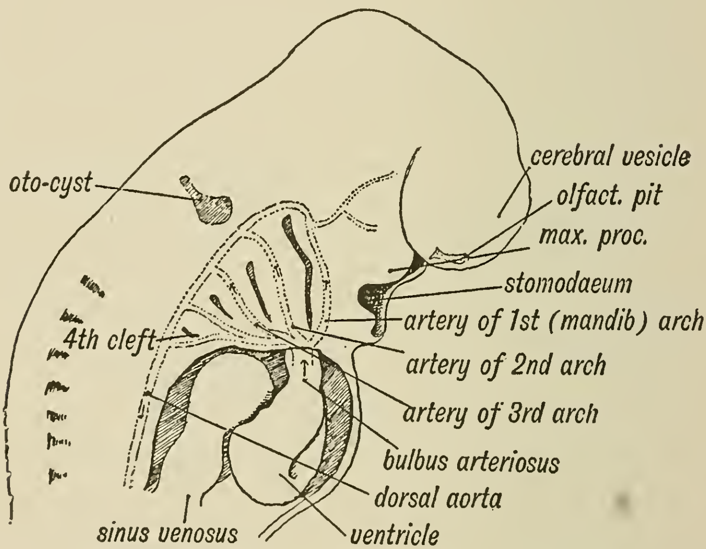

FIG. 20.—SHOWING THE VISCERAL ARCHES AND THE CLEFT DEPRESSIONS IN THE PHARYNGEAL WALL OF A HUMAN EMBRYO AT THE BEGINNING OF THE FOURTH WEEK. (After His.)

Each visceral arch contains an aortic arch.

Its structure during this period is passing through stages in its development which are common to it and the fish, and the fact that these piscine characters in the human embryo retrogress without being completed, indicates that they are there as remnants of an early ancestor which at one time completed its existence as a fish. For instance the beginnings of the nasal fossæ are two pits which later communicate with the oral cavity by open grooves.

The Branchial Arches—Again the heart begins its development high up in the embryo immediately beneath the mandible. There

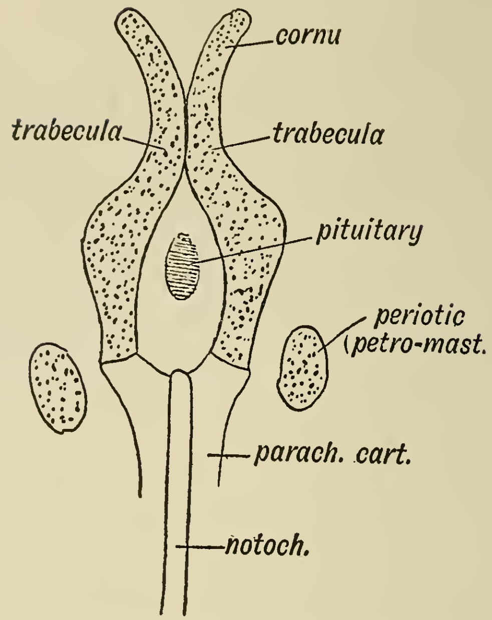

Fig. 21.—Diagram of the Trabeculæ Cranii, Parachordal Cartilages, and Periotic Capsules.

is, therefore, at this stage, as in the fish, no neck. Moreover, at about the fourth week there appear in the lateral walls of the pharynx, encircling it from the back forwards, four elevations,

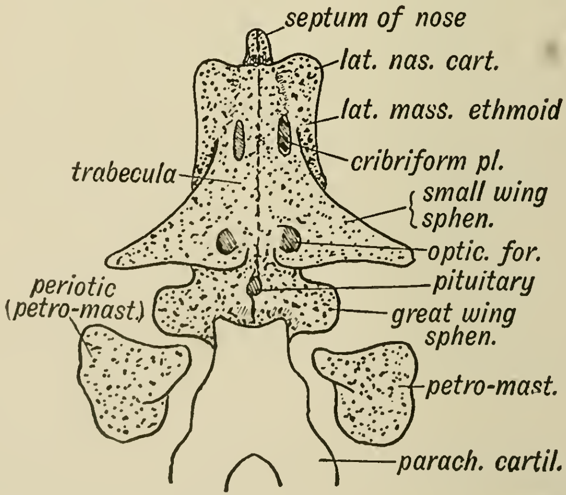

Fig. 22.—Diagram of the Structures Formed from the Trabeculæ Cranii.

separated by grooves. (Figs. 20, 21 and 22.) These elevations represent incompletely separated visceral arches, which at a later

stage in the fish, become completely separated by the grooves, becoming transformed into clefts. These arches correspond to the gills of the fish, and are called the branchial arches.

The mandibular and hyoid processes are also called the mandibular and hyoid arches, and by this nomenclature there are six branchial arches. The mandibular and hyoid arches in the fish increase at a much greater rate than the four remaining branchial arches below them. The mandibular arch bounds the visceral cavity and the hyoid forms the operculum for the gills. In the human embryo it outgrows the next two arches.

By the end of the second month all the clefts or grooves except the upper part of the first have disappeared. From the uppermost portion of this cleft a solid ingrowth of epithelium takes place, and this ingrowth later becomes transformed into a canal, the canal of the external auditory meatus.

Meckel Cartilage and the Development of the Ear—A cartilage develops in the first, or mandibular, arch, which is known as Meckel's cartilage. (Fig. 23.) From Meckel's cartilage is formed the body of the lower jaw and the malleus. The joint between the malleus and incus represents the original inferior maxillary joint. As evolution from the piscine stage proceeds the malleus becomes appropriated from the lower jaw by the organ of hearing and the lower jaw forms a new articulation with the squamous portion of the temporal bone. The membrana tympana represents the thin tissue occupying the upper part of the first cleft and lies exposed upon the surface of the skull. It is supported in a delicate osseous ring, the tympanic ring. This is developed in connection with the cartilages of the first and second arch, and during the subsequent course of development, and even for a long time after birth, it increases in thickness to form the tympanic plate and the bony portions of the external auditory meatus and floor of the Eustachian tube.

The ramus of the lower jaw must be regarded as an addition developing as an ascending process from the primary jaw of the fish.

Fig. 23 shows the structures developed from the other arches. The tonsil is developed between the second and third arches in the position of the second cleft. The pyriform fossa at the side of the larynx is in the position of the fourth and fifth clefts.

The hyoid bone probably represents fused portions of the cartilages belonging to the second and third arches, the lesser process and the stylo-hyoid ligament representing the second arch, and the greater horn the cartilage of the third arch.

The Development of the Circulation—The most primitive form of heart is tubular, and is divided into four chambers, which are arranged in a line with each other. (Fig. 24.) These chambers are the sinus venosus, which receives the blood from the liver; the auricle; the ventricle; and the bulbus cordis, or arteriosus,

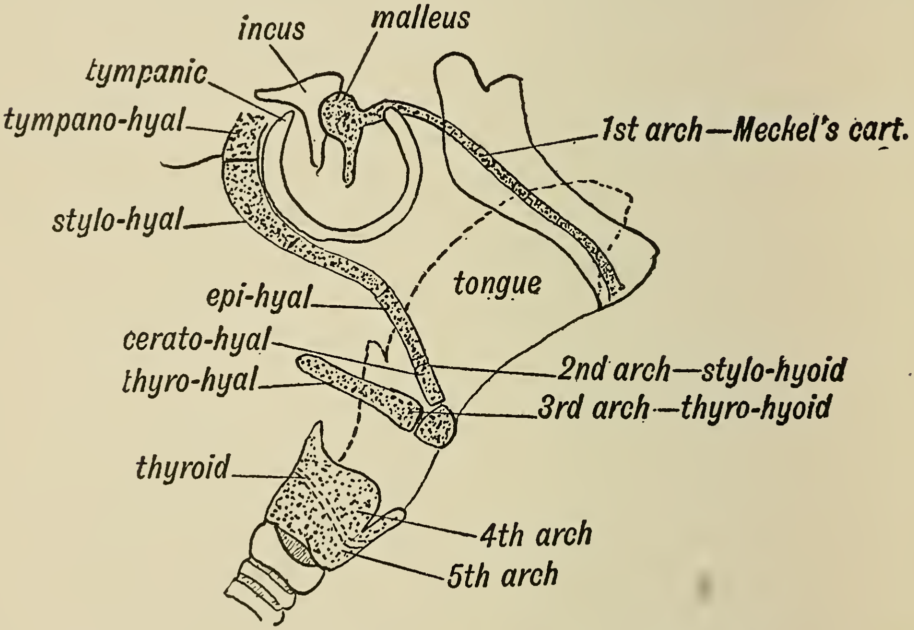

Fig. 23.—Showing What Becomes of the Cartilages of the Visceral Arches.

from which the ventral aorta arises, the vessel which carries the blood to the branchial arches. The primitive heart is, therefore, little more than a tubular pump, receiving at one end venous blood, which has passed through the liver, and pumping this out at the other end into the apparatus for respiration.

The Primitive Circulation—In the human being the heart also originates as a tubular pump. There are at first two such tubular organs on each side of the body. These appear at the end of the second week. They appear toward the cephalic end of the embryo, in the lateral portion of the mesoblastic tissue, inserting themselves between the epiblast and hypoblast from the

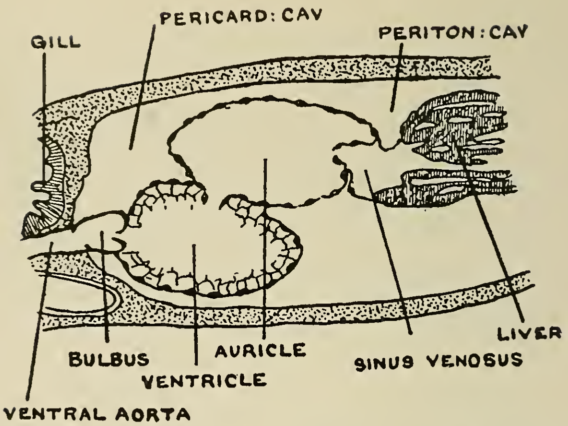

Fig. 24.—The Heart of Ammocœtes Seen in a Median Section. (After Vialleton.)

cœlomic cavity. (Fig. 25.) This primitive heart pumps blood through a capillary circulation developing in the archenteron or yolk sac. (Fig. 26.)

At the beginning of the third week, when the head and tail

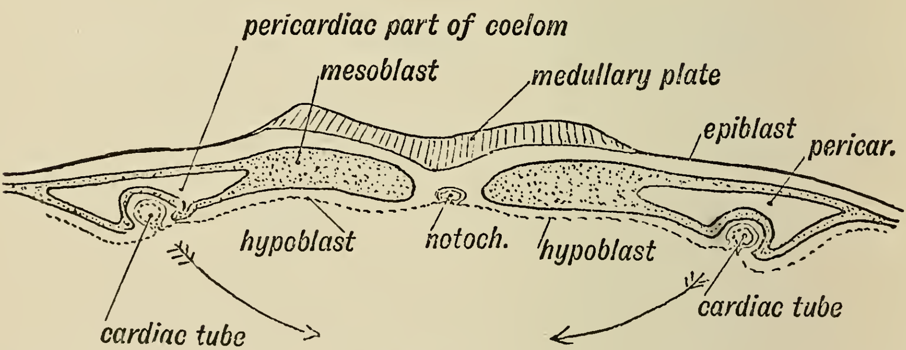

Fig. 25.—Transverse Section of Embryonic Plate Showing the Right and Left Cardiac Tubes in the Splanchnopleure.

The arrows indicate the approximation of the sides of the body wall which takes place after the outgrowth of the fore-gut.

folds form, the right and left cardiac tubes approach each other, between the archenteron and the gut, and fuse. At the beginning of the third week the heart lies free in the anterior extremity of the body cavity, and, inasmuch as at this time there is only one body cavity, it may be called the pericardial or pleuroperitoneal cavity. The heart is fixed at its anterior and posterior ends by the vessels entering and leaving it, and the folds of somatopleura around them.

The Primitive Venous System—The venous channels bringing the blood to the heart are the right and left ducts of Cuvier, two large venous channels encircling the body wall from behind forward, and formed behind by the union of the anterior cardinal or primitive jugular veins, returning the blood from the anterior half of the body, and the posterior cardinal vein, returning the blood from the posterior half of the body. (Fig. 27.)

The cardinal veins lie in the mesoblast on the dorsal side of the cœlom at the juncture of the somatopleure and splanchnopleure.

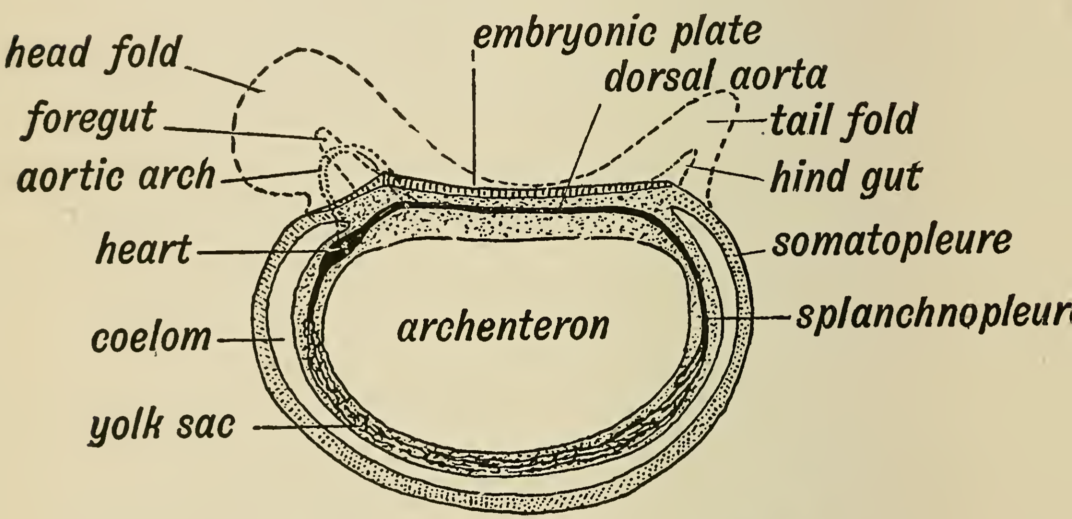

Fig. 26.—Diagram Showing the Relationship of the Heart to the Archenteron of the Developing Ovum. (After A. Robinson.)

The outgrowth of the head fold is indicated carrying a process (fore-gut) of the archenteron and also the aorta and heart. The outgrowth of the tail fold and hind-gut is also shown.

The ducts of Cuvier pass from behind forward in the somatopleure and enter the heart in its anterior attachment, forming this by a fold of somatopleure, known as the septum transversum.

The terminal part of the right primitive jugular vein and the right duct of Cuvier form the superior vena cava of the adult. (Figs. 28 and 29.) The left duct of Cuvier begins to disappear at about the beginning of the second month, at a time when the auricles of the heart are beginning to be separated from each other. All that remains of the left duct of Cuvier in the adult is the oblique vein of Marshall.

The left superior intercostal vein of the adult represents;

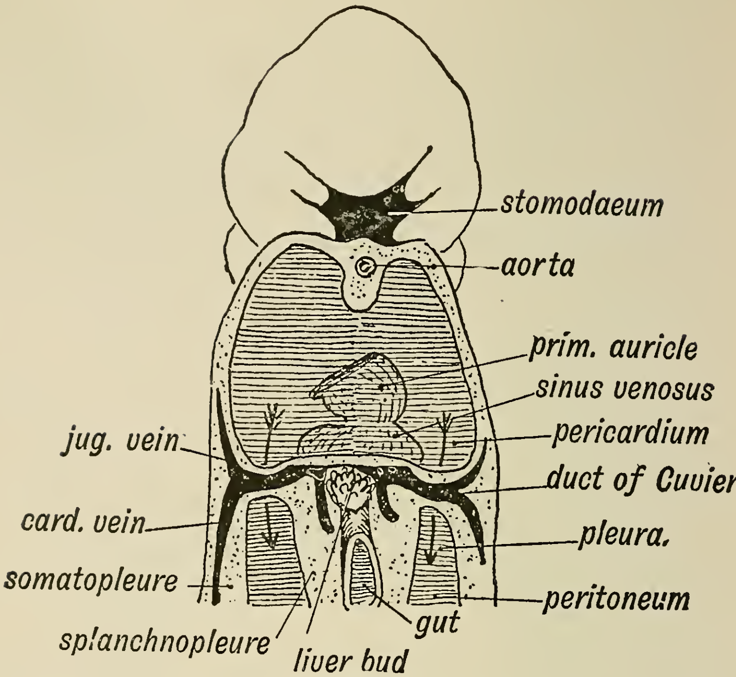

FIG. 27.—DIAGRAM TO SHOW THE MANNER IN WHICH THE DUCTS OF CUVIER ENCIRCLE THE CŒLOM AT THE JUNCTION OF THE PERICARDIAL AND PERITONEAL PASSAGES AT THE THIRD WEEK. (After His.)

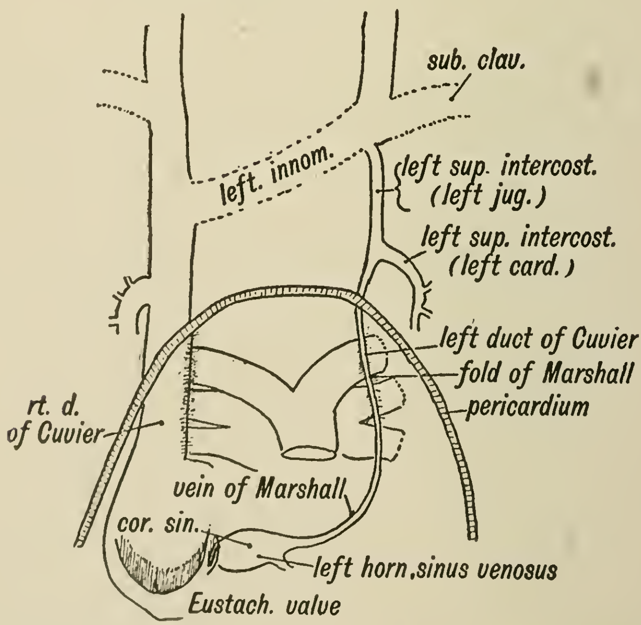

FIG. 28.—THE REMNANTS OF THE LEFT SUPERIOR VENA CAVA.

1. The anterior part of the left posterior cardinal vein.
2. The extra pericardial part of the left duct of Cuvier.
3. The terminal part of the left primitive jugular vein.

The atrophy in the left duct of Cuvier is induced by the opening up of a new channel between the two primitive jugular veins. This new channel becomes subsequently the left innominate vein.

The subclavian veins develop with the budding and growth of the limbs from one of the segmental tributaries of the anterior cardinal or primitive jugular vein.

In the same manner the common iliac veins develop from in-

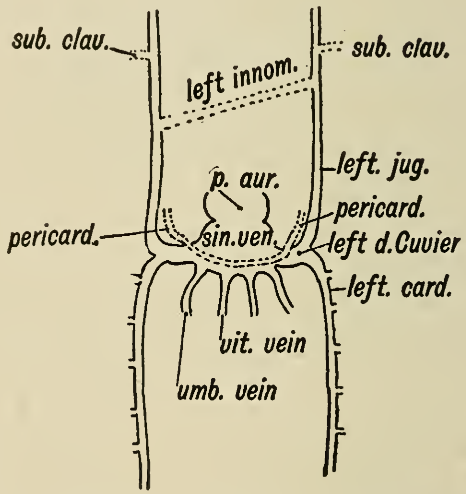

Fig. 29.—Diagram of the Sinus Venosus and Ducts of Cuvier of the Human Embryo About the Third Week.

tersegmental tributaries of the posterior cardinal veins at the time of the budding and growth of the lower limbs.

The posterior or postnephric portion of the right posterior cardinal vein forms the posterior portion of the adult vena cava. (Fig. 30.) The prenephric portion of the right cardinal vein becomes the vena azygos major.

The supradiaphragmatic portion of the inferior vena cava is formed from the terminal part of the vitelline veins, which pass to the cardinal vein from the ventral mesentery of the foregut. The prenephric portion of the inferior vena cava, uniting the postnephric portion and the supradiaphragmatic portion, is developed as a new channel between these portions at the beginning of the

second month, when the cardinal veins are broken up by the descent of the mesonephros, and thus provides for a short circuiting of the blood to the heart.

The two vitelline veins end in the posterior chamber of the

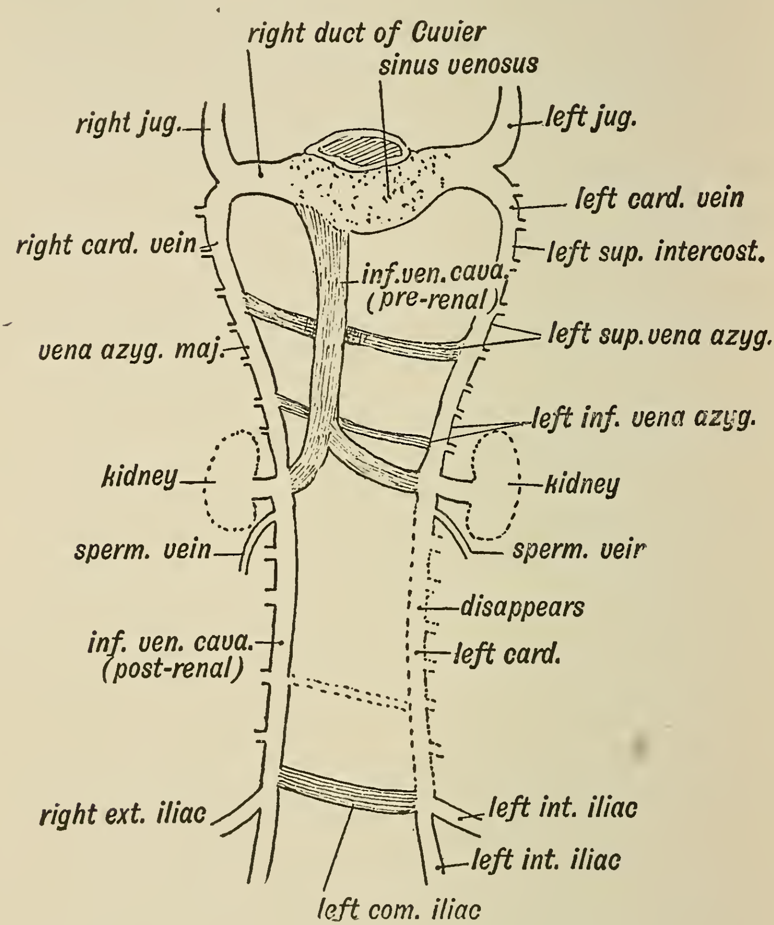

Fig. 30.—The Remnants of the Posterior Cardinal Veins in the Adult. (After Hochstetter.)
The new channels are shaded.

tubular heart, the sinus venosus, and return the blood in the ventral mesentery of the foregut from the yolk sac. (Fig. 29.) The two vitelline veins enclose the duodenum and unite at the site of the transverse fissure of the liver, thus forming the portal sinus.

The vitelline veins may be divided into three portions (Fig. 31):

1. The portion in the gastrohepatic omentum or ventral mesentery.

2. That portion in the neck of the pancreas.

3. That portion in front of the third portion of the duodenum.

It must not be forgotten that the duodenum at first lies free in the peritoneal cavity possessing a true mesentery. The liver is

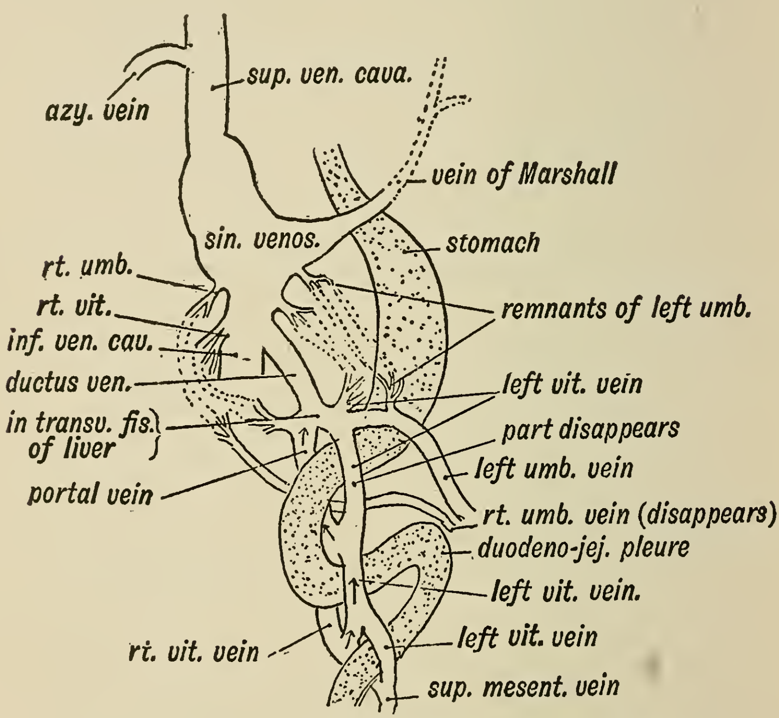

FIG. 31.—DIAGRAM SHOWING THE FORMATION OF THE DUCTUS VENOSUS, AND THE FATE OF THE UMBILICAL AND VITELLINE VEINS.

The arrows show the parts of the vitelline veins which become the portal vein.

developed in its ventral mesentery and the pancreas in its dorsal mesentery.

The portal vein then becomes formed from the following portions of the right and left vitelline veins:

1. The portal sinus at the transverse fissure of the liver from the union of the two vitelline veins.

2. The portion of the portal vein in the gastrohepatic omentum from the right vitelline vein. The corresponding portion of the left vitelline vein disappears.

3. The portion of the portal vein at its commencement at duodeno-pancreatic juncture from the juncture of the two vitelline veins at this place, the superior mesenteric vein being derived from the left vitelline vein, while the corresponding portion of the right disappears.

In addition to the vitelline veins the umbilical veins also pass to the liver. These carry the return blood from the placenta

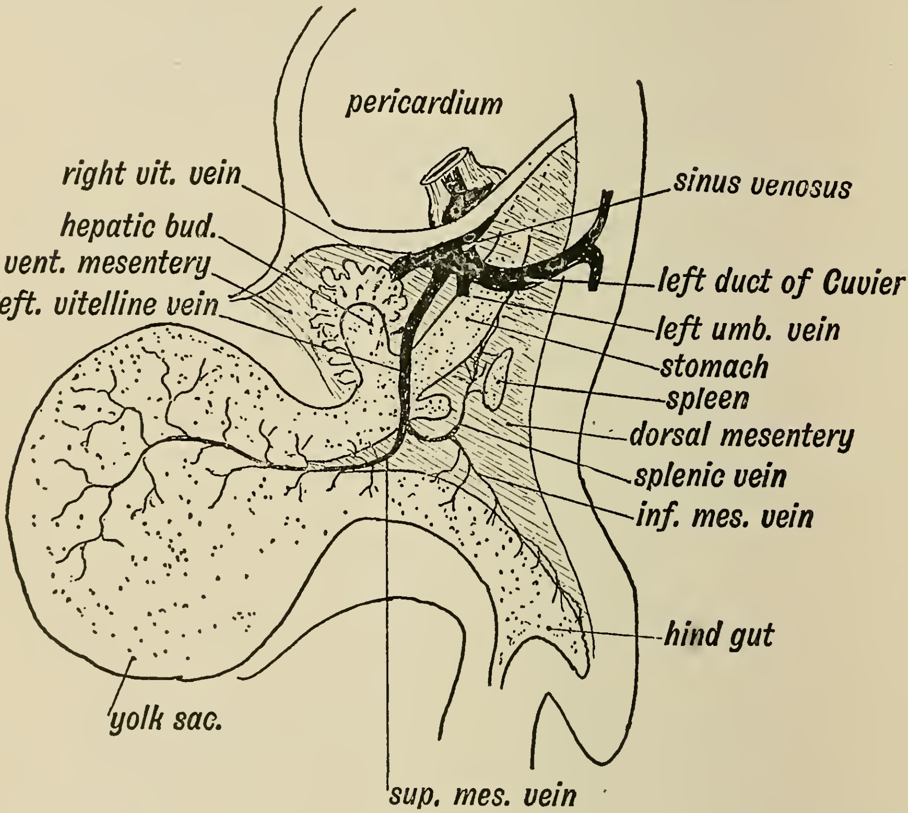

Fig. 32.—The Left Vitelline Vein of an Embryo of the Fourth Week.

through the umbilical cord and, enclosed by the ventral mesentery, or that portion of it named the falciform ligament, to the anterior half of the longitudinal fissure of the liver. Here the umbilical veins join the portal sinus.

In the fifth week of intra-uterine life a new channel develops between the portal sinus and the terminal part of the right vitelline vein above the liver. This new channel develops into a vein of considerable size and is called the ductus venosus. By means of it most of the blood returned through both the portal vein and

the umbilical vein passes directly to the heart without passing through the liver.

Before the ductus venosus is developed, the liver bud (Fig. 32), springing from the primitive duodenum, grows around and through the portions of vitelline and umbilical veins at this site, breaking up these vessels into an anastomosing network, and eventually forming the hepatic network of veins, having the relation to the hepatic lobules which is present in the adult.

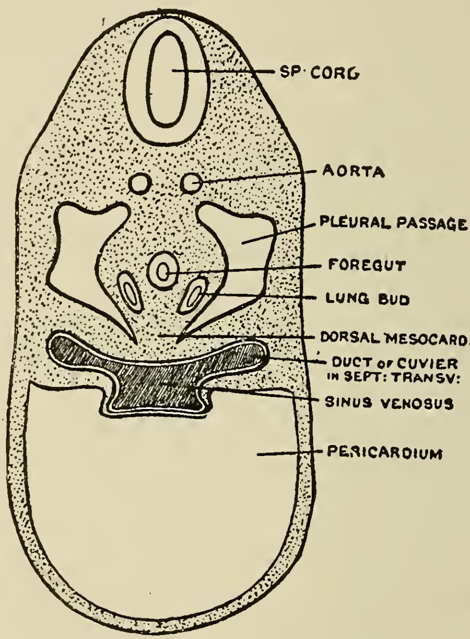

Fig. 33.—Diagrammatic Section Across an Embryo of the Third Week to Show the Relationship of the Sinus Venosus to the Septum Transversum and Dorsal Mesocardium.

The Arterial System—The earliest form of the heart, as has been explained, is simply a bilateral tubular pump. At the end of the second week the two hearts fuse and form a single tubular pump. Four very definite portions become differentiated in this tubular pump:

1. The first portion receiving the blood from the duct of Cuvier. This portion is called the sinus venosus, and it lies in the transverse septum which incompletely separates the peritoneal cavity from the pericardial or pleural cavity.
2. The second portion, the primitive auricle.
3. The third portion, the primitive ventricle.

4. The fourth portion, the bulbus arteriosus, or bulbus cordis.

The heart at first lies in a dorsal and ventral mesentery. The dorsal mesentery disappears. The heart then is suspended free in the cœlomic cavity by the union of the two vitelline veins passing to it in the duct of Cuvier in the ventral mesocardium, and by the two aortic arches emerging at the other end of the tubular heart in front. (Figs. 33 and 34.) These arches pass forward along the

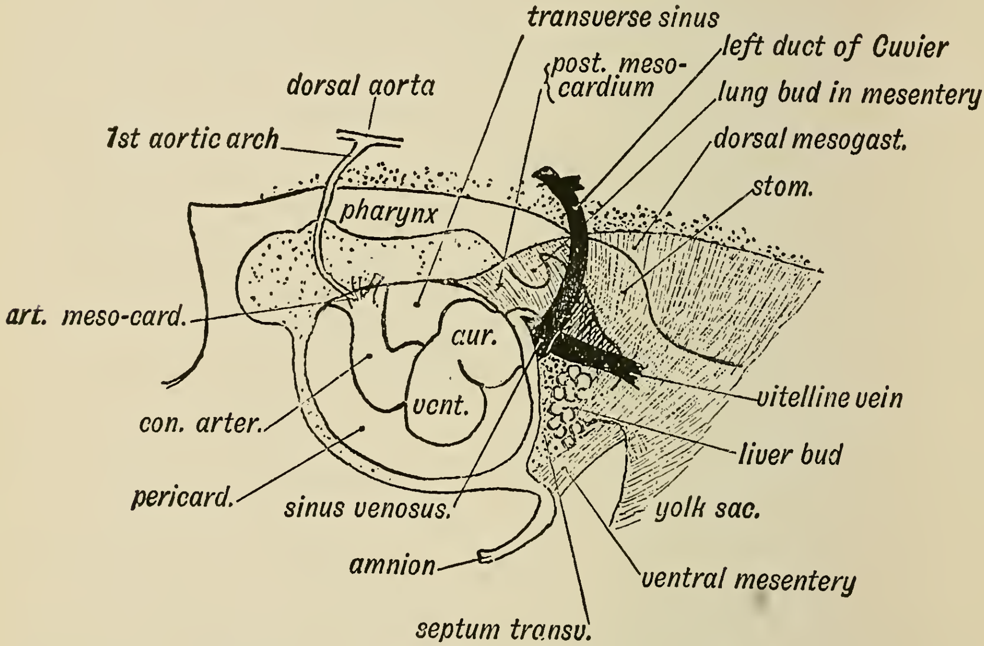

Fig. 34.—The Mesentery of the Fore-gut and Its Contents, Viewed from the Left Side. (Schematic.)

floor of the pharynx, one on each side, and give off six branches, one to each branchial cleft. The branchial branches empty into the dorsal aortæ. The first and second arches disappear almost as soon as formed. The third persists as the internal carotid. (Figs. 35 and 36.) The fourth right forms the first and second portions of the right subclavian. On the left side the fourth forms part of the aortic arch. The fifth only persists a short time. The sixth forms the right and left pulmonary arteries, and on the left side the ductus arteriosus.

The ventral aortæ elongate into the innominate and common carotid arteries. The left dorsal aorta below the fourth arch per-

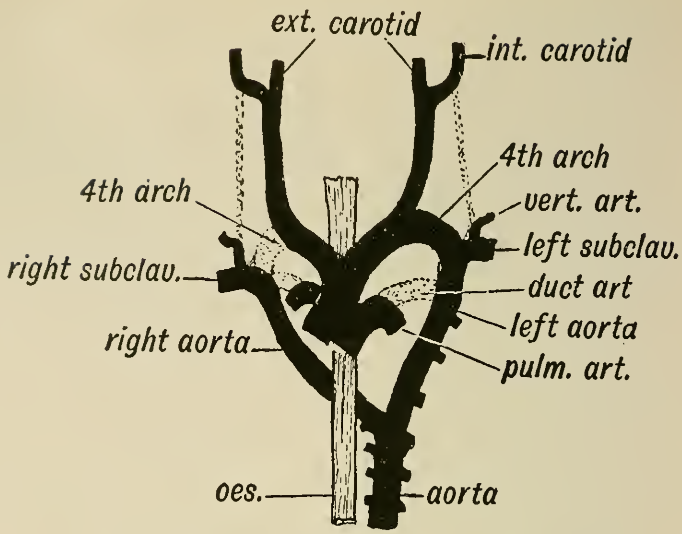

FIG. 35.—DIAGRAM SHOWING THE MANNER IN WHICH THE RIGHT SUBCLAVIAN MAY ARISE AS THE LAST BRANCH OF THE ARCH OF THE AORTA.
The parts of the aortic arch system which become obliterated are stippled.

sists as the descending aorta, while the right dorsal aorta disappears.

The Analogy of the Primitive Human Circulation to That of the Fish—Thus it is appreciated that the primitive human heart is tubular like the fish, and also, as in the fish, it pumps the blood

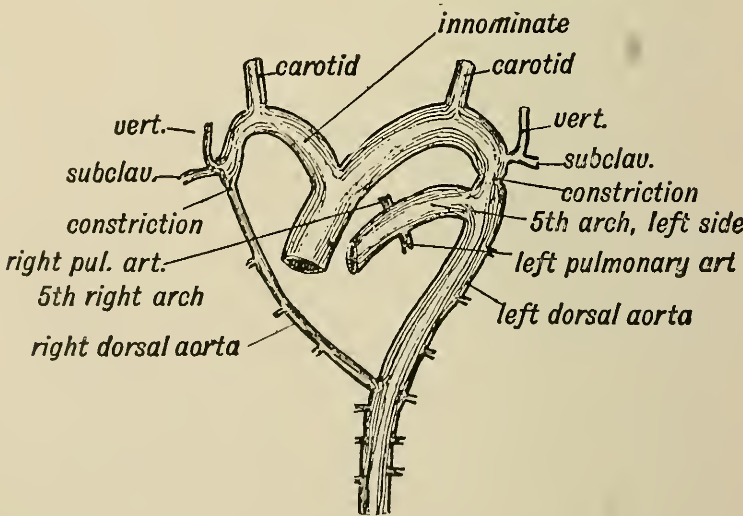

FIG. 36.—THE CONDITION OF THE RIGHT AND LEFT DORSAL AORTÆ IN A SIXTH WEEK HUMAN FETUS. (After His.)
The right arch disappears beyond the origin of the right subclavian; a constriction may appear at the corresponding point on the left side.

into a system of branchial arches which in the fish pass through the gills, and that the blood purified by its passage through the gills passes to the rest of the body by the dorsal aortæ.

In the human being the respiratory function of the gills has been replaced by the lungs, which are new structures; yet these are still supplied by branchial vessels, the sixth branchial arches.

The Change in the Heart from the Tubular to the Adult Type —Coincident with these changes, and doubtless making them pos-

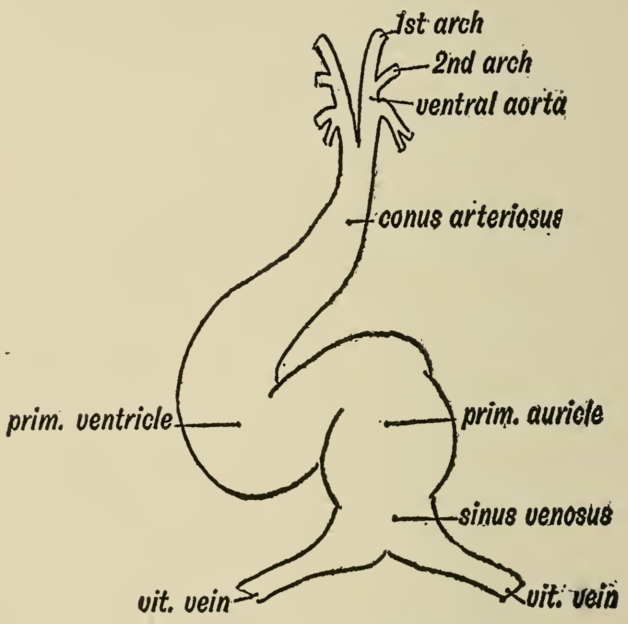

FIG. 37.—THE PRIMITIVE DIVISIONS OF THE EMBRYONIC HEART.

sible, the heart itself has become transformed by a double twist from a simple tubular structure to a four-chambered organ receiving and discharging the blood at the same end.

One of these bends is the ventricular bend. The ventricle becomes bent into a V-shaped structure, so that the discharging end of the ventricle comes to lie close to its receiving end. The other bend is the auriculoventricular bend, in virtue of which the ventricle twists around in front of the auricle and comes to lie in front and to its left, the apex of the V produced by the ventricular bend pointing to the right. (Compare Fig. 37 and Fig. 38.)

The next important change is the division of the heart into its four chambers. During the last of the first month and beginning of the second month the primitive single auricle becomes

separated into a right and left auricle by the formation and union of three septa. These septa spring from the walls of the auricles, and grow in toward the center of the cavity of the auricle. The communication between the two auricles does not completely close till after birth. Before birth a large part of the venous blood passes from the right auricle directly to the left and thence into

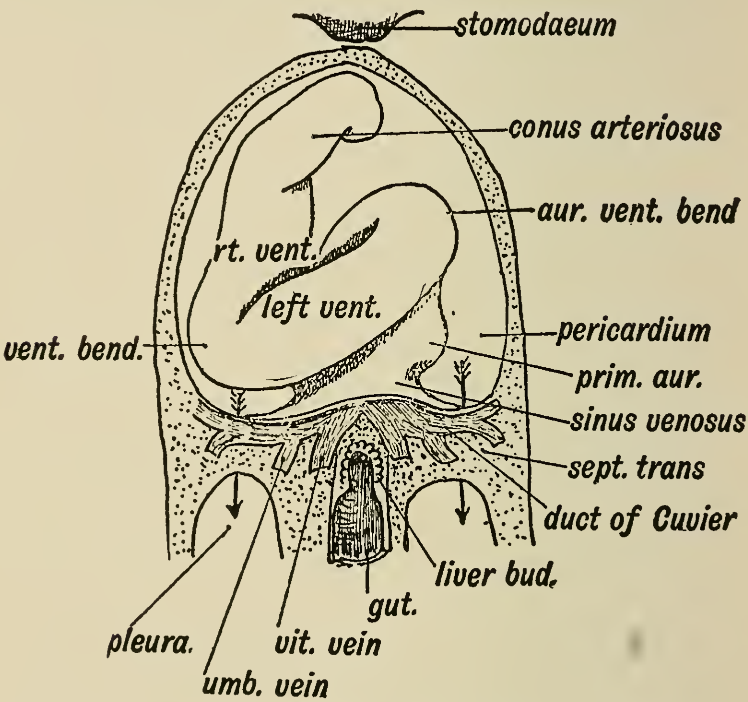

Fig. 38.—Showing the Two Chief Bends Which Occur in the Heart During the Third Week.

the left ventricle, thus reaching the systemic circulation without travelling through the lungs.

As the primitive auricles become divided into two auricles, so the primitive bulbus arteriosus and ventricle become partitioned into two cavities by the growth of septa from opposite portions of the walls of these cavities. While the auricles are being divided the conus arteriosus becomes divided by septa which unite in the form of a spiral in such a manner that the conus arteriosus at one end is divided into two vessels opening into halves of the primitive ventricular cavity, which subsequently become the right and left ventricles, while at the other end both the sixth pair of bran-

chial arches open into the half of the divided aorta which opens from the right ventricle.

The musculature of the lateral and convex aspects of the ventricle grows rapidly so that the cavity becomes nearly filled with a sponge-work system of trabeculæ. (Fig. 39.) In fishes this network largely persists, but in birds and mammals it becomes absorbed to form the ventricular cavities. Between excavations on the right and left side enough of the muscular tissue is left to form the interventricular septum. A foramen may persist at the

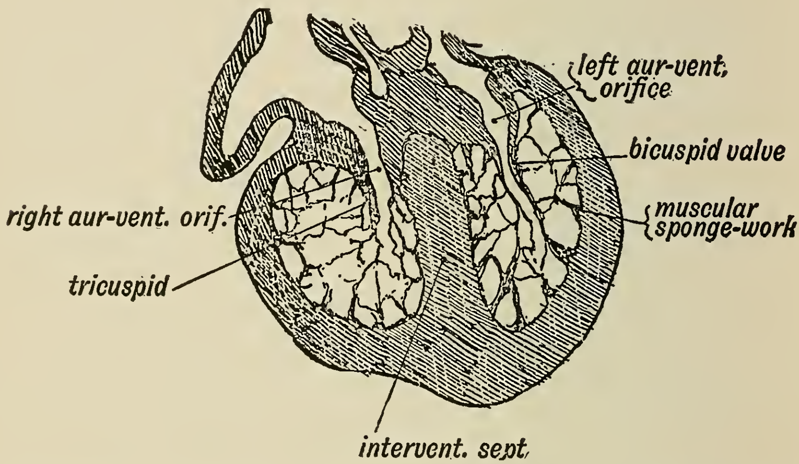

FIG. 39.—SECTION OF THE VENTRICLES OF THE FETAL HEART, SHOWING THE MUSCULAR SPONGE-WORK WITHIN THEIR CAVITIES. (After His.)

upper part of this septum after birth. It is known as the interventricular foramen.

The direct passage between the auricles through the foramen ovale is not the only provision for diverting the blood stream from the lungs. The sixth left branchial arch forms not only the left pulmonary artery, but the ductus arteriosus. (Fig. 35.) This artery connects in later fetal life the left pulmonary artery with the arch of the aorta, and therefore serves to transmit a large part of the blood leaving the right ventricle from the pulmonary artery to the arch of the aorta.

The Circulatory Changes Occurring at Birth—With the first expansion of the lungs after birth, the blood becomes drawn into the lungs through the pulmonary artery, and finds less resistance through this route than through the ductus arteriosus, within which

it meets the aortic blood pressure. The ductus arteriosus, therefore, soon closes after birth.

With the ligature of the umbilical cord and the cessation of the large flow of blood through the umbilical veins, the ductus venosus also closes, and the venous blood finds its way through the liver into the right auricle through the right ventricle and into the pulmonary arteries and lungs.

Thus it is that the primitive tubular heart and branchial respiratory system of the fish becomes transformed into the more com-

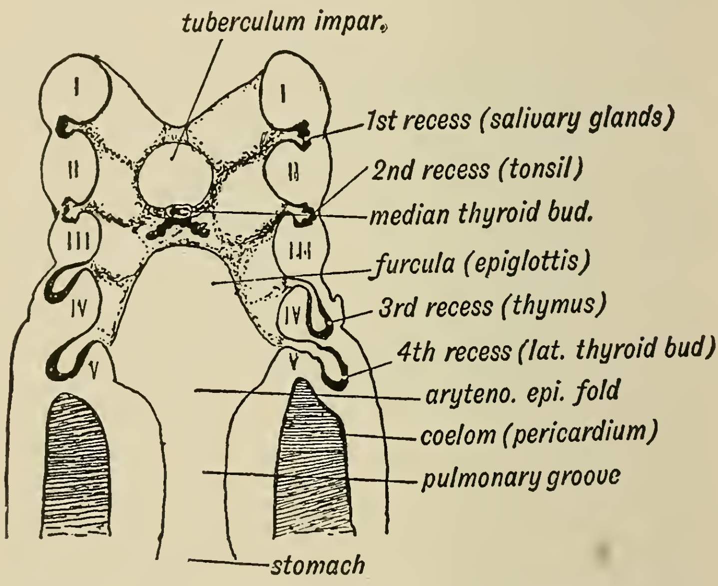

Fig. 40.—Floor of the Pharynx and Esophagus of a Human Embryo of Three Weeks, Showing the Furcula, Pulmonary Groove and Diverticulum. (After His.)

plicated four-chambered heart of the human being, adapted for the totally different respiratory system of man.

The Development of the Lungs—The lungs themselves, as the other glands, develop from the gut; the liver and pancreas grow from buds which spring from the primitive alimentary canal. At the end of the third week a deep groove (Fig. 40) appears in the floor of the primitive pharynx and esophagus. This groove commences between the fifth and sixth visceral segments, and reaches almost to the stomach. It must be remembered that at this period there is no real neck, and the whole esophagus is very short.

The anterior margins of the groove unite and from the anterior

extremity the epiglottis is formed. The anterior margins of the lateral walls of the groove form subsequently the true vocal cords. Soon the posterior margins of the lower portions of the groove unite, and thus a true pouch lying in front of the esophagus becomes separated off from the esophagus. (Fig. 41.) This pouch lies with the esophagus in the dorsal mesentery. It is the pulmonary pouch or pocket. In the fourth week its lower or posterior extremity gives rise to two lateral buds. (Fig. 42.) From these

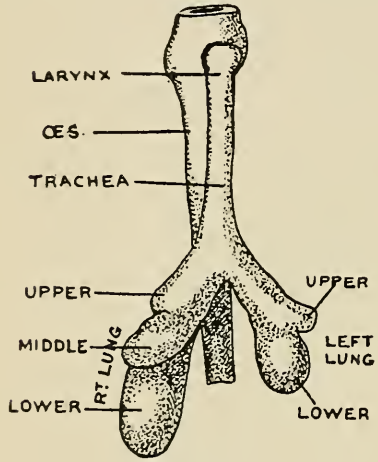

FIG. 41

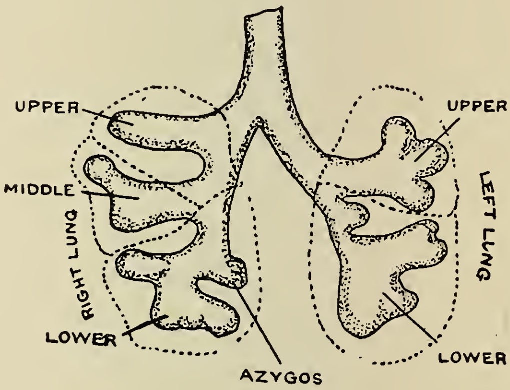

FIG. 42

FIG. 41.—THE TRACHEA, BRONCHI AND LUNG BUDS IN THE FOURTH WEEK OF DEVELOPMENT. (After Broman, *Entwickelung des Menschen,* 1911.)

FIG. 42.—THE LOBULATION OF THE LUNGS EARLY IN THE FIFTH WEEK. (After Merkel.)

buds the two lungs are formed. They increase in size and push their way into the portion of the cœlomic cavity surrounding the pericardium. As they do so they push the lining mesoblast of the cœlomic cavity in front of them, invaginating it into the space around the pericardium. In this manner the pleural cavities are formed.

The Development of the Liver and Pancreas—Nothing need be added regarding the formation of the liver and pancreas to what has already been explained about their formation in connection with the circulation by a process of budding from the foregut. (Fig. 43.)

The Development of Stomach and Lesser Peritoneal Sac—The formation of the lesser peritoneal cavity and the position occupied

by the stomach is easily comprehended by remembering that when first formed the stomach possesses a dorsal and ventral mesentery, and lies in the sagittal plane of the body. By a rotation of the pyloric end of the stomach to the left, and a shortening of the portion of its ventral mesentery, to form the gastrohepatic omentum, the foramen of Winslow and lesser peritoneal cavity are formed, and the stomach is brought to occupy the coronal plane.

The Development of the Urogenital Tract—The development

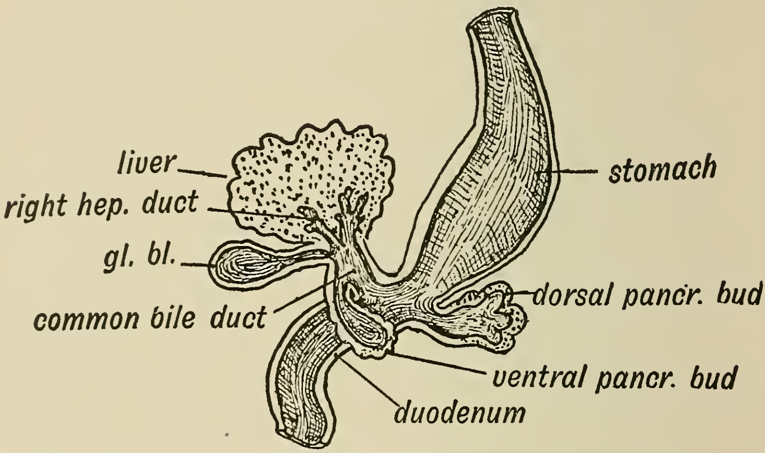

FIG. 43.—THE PANCREATIC AND HEPATIC PROCESSES OF A FOURTH WEEK HUMAN EMBRYO. (After Kollmann.)

of the urogenital tract is somewhat more complicated, and requires a slightly more amplified description.

As has been explained, the urogenital tract develops from cells retaining epithelial characters and situated upon the genital ridge of the intermediate cell mass of the mesoblast. (Fig. 15.) Upon this ridge in the anterio-posterior direction of the human embryo, and toward the end of the third week, there are three nephric organs. These make their appearance one after the other, and represent corresponding nephric organs which make their appearance successively in the evolution of vertebrate animals. The first of these is the pronephros. It is on a level with the septum transversus, and persists but a short time. (Fig. 44.) The second is the mesonephros, or Wolffian body. It is on a level with the segments of the dorsal and lumbar regions. The third is the metanephros, which becomes later the kidney, and lies ventral to the

sacral vertebræ. All these organs are made up of tubules opening into a common duct.

In the fish and amphibian the Wolffian body functionates as a kidney. This kidney function became relegated, as life became more highly developed, to the hindermost portion of the mesonephros, and in the human being a posterior portion, the metanephros, quite separated from the remainder of the organ. Meanwhile the anterior portion became devoted solely to reproductive functions.

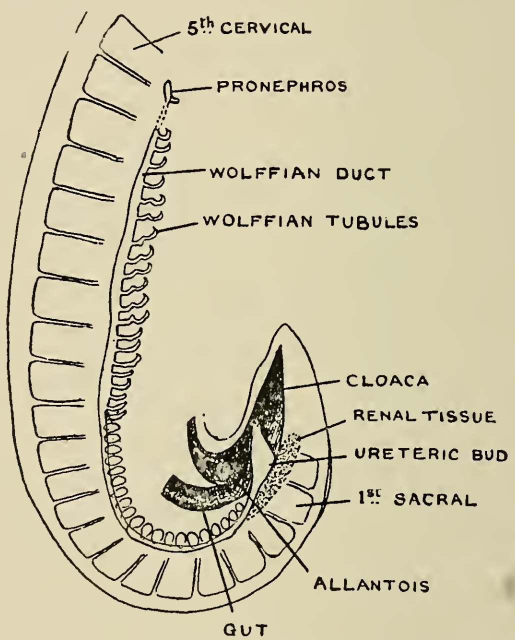

Fig. 44.—Condition of the Nephric or Renal Tissue in a Human Embryo of Three Weeks. (After Ingalls.)

In the frog the Wolffian duct conveys both spermatozoa and urine to the cloaca. In the human embryo at the beginning of the second month the Wolffian body is well developed. By the end of the second month all of the Wolffian body, except that portion which becomes devoted to reproduction, atrophies.

Though the complete kidney apparatus comprises the pronephros, the mesonephros and the metanephros, and the tubules of all these organs open into the Wolffian duct, yet certain of the cells of this region, in particular in the region of the mesonephros and lining ducts, which also open into the Wolffian duct, must, from the first, be set aside for reproductive purpose, and form the reproductive

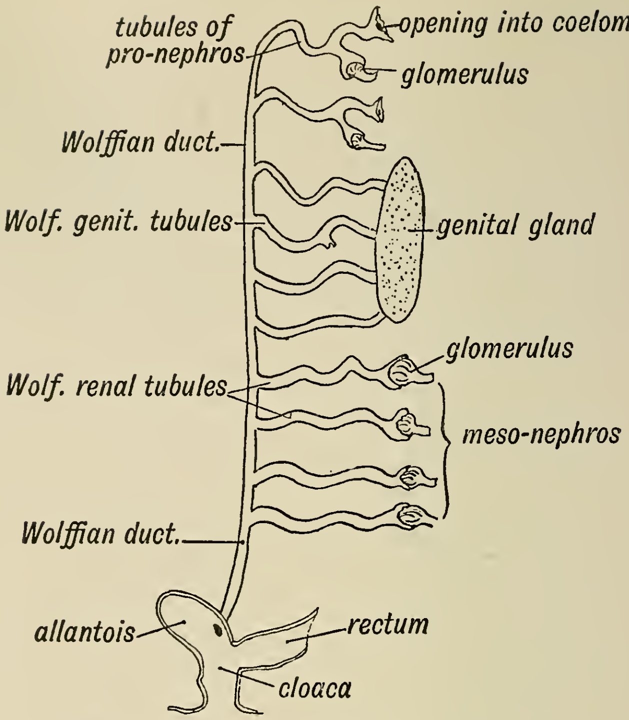

FIG. 45.—SCHEME OF THE WOLFFIAN BODY ON THE RIGHT SIDE.

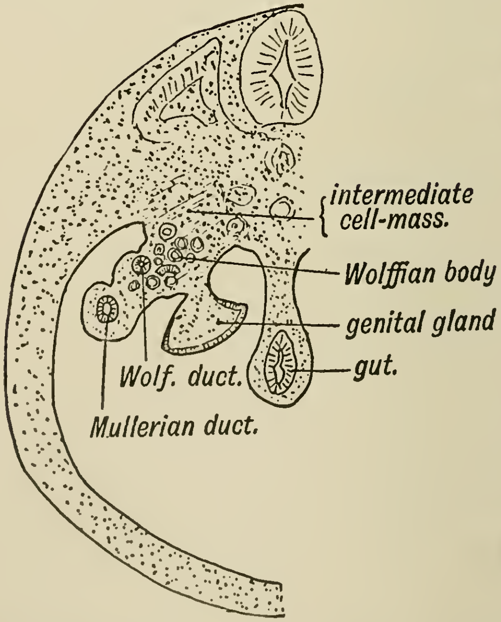

FIG. 46.—DIAGRAMMATIC SECTION TO SHOW THE POSITION OF THE WOLFFIAN AND GENITAL RIDGES ON THE DORSAL WALL OF THE ABDOMEN.

glands. This is also indicated by the fact that, on the genital ridge, the genital gland and Wolffian body possesses separate mesenteries, though the two mesenteries possess a common attachment. (Compare Figs. 45 and 46.)

The Wolffian duct is developed by an invagination of the more external portions of the lining of the genital ridge. From it in the adult are developed the ureter and in the male the vas deferens.

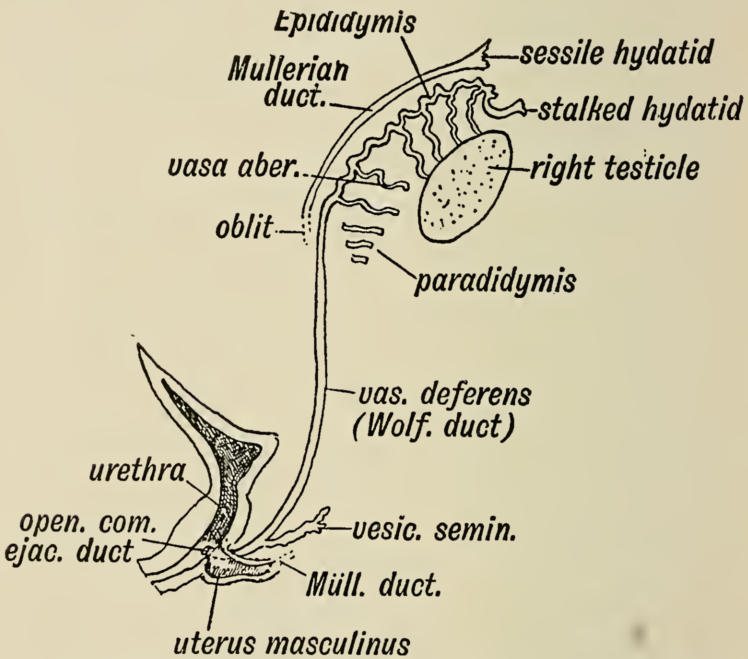

Fig. 47.—Remnant of the Wolffian Body in the Male.

In the female the vestigial remnants of the vas is the parovarium and ducts of Gartner. A little more external, still another similar invagination forms another duct, Müller's duct. From Müller's duct are developed the uterus and Fallopian tubes; in the male the vestigial remains of these structures form the sinus pocularis and the hydatid of Morgagni.

To sum up, therefore, by a differentiation of cells arising in but slightly different locations on the genital ridge, two glands, the genital gland and the kidney, and two ducts, the Wolffian duct and Müller's duct, arise. The kidney, at first occupying the whole longitudinal distance of the genital ridge, becomes later restricted to its posterior portion. The genital gland arises from above the kidney in approximately the middle of the length of the genital

ridge. The tubules of both glands open into the Wolffian duct. Both the Wolffian duct and Müller's duct open into the common cloaca (Fig. 45) in the lower vertebrates. In the higher mammals and human beings the cloaca becomes separated into a urogenital passage and the rectum.

In the male and female the following organs become developed from the various embryonic structures which have been mentioned. (Figs. 47 and 48.) In both male and female the kidney becomes

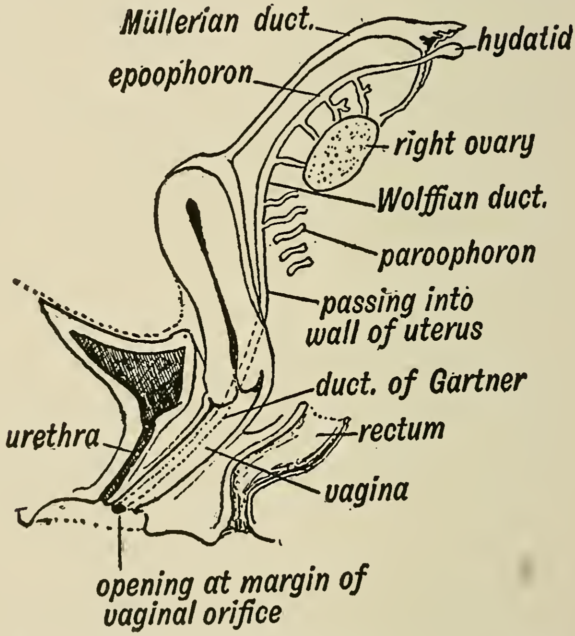

Fig. 48.—Remnants of the Wolffian Body in the Female.

developed from the posterior tubules of the Wolffian body or metanephros. Its tubules empty into the ureter, which develops from a portion of the Wolffian duct.

In the male the genital gland becomes the testis. Its tubules empty into the vas deferens, which is the adult representative of a portion of the Wolffian duct. The testes in late fetal life undergo a long descent and by this process reach the scrotum; for this reason the vas deferens possesses a different direction than the ureter. The posterior urethra represents that portion of the cloaca receiving the urinary and genital ducts.

Müller's duct is also formed in the male, but it persists as a vestigial structure, branching off from the vas within the epi-

didymis, the so called hydatid of Morgagni, and as a second little diverticulum from the prostatic urethra called the sinus pocularis or uterus masculinus.

In the female the genital gland forms the ovary, and Müller's duct forms the Fallopian tube and uterus. (Fig. 48.) The genital portion of the Wolffian duct persists as a vestigial structure, the epoöphoron. This structure is situated between the Fallopian tube and the ovary, and receives a number of tubules passing from the direction of the ovary to it. They constitute the organ of Rosemüller or the parovarium. The lower end of the Wolffian duct may not completely disappear, but may form a tubular diverticulum from the vagina, as the duct of Gartner. The cloaca in the female is represented by the introitus, which receives the urethra and the vagina.

The Changes in the Female During Pregnancy—*The Changes Occurring within the Uterus during Pregnancy*—The full development of the fertilized ovum into the child at term involves, not only the complicated folding and differentiating processes which produces a normally formed human being, weighing eight pounds from the single ovum, which measures, when it sinks into the cavity of the uterus, one millimeter in diameter, but also involves the enlargement and preparation of the uterus for the developing child.

The virgin uterus is pear shaped and possesses a capacity of only two to five centimeters. The uterus at term possesses a capacity of five to seven thousand centimeters. Its walls are immensely thickened. This hypertrophy probably does not involve a production of new muscular tissue, but an enlargement of each individual fiber. Its mucous membrane attains a thickness of ¾ of a centimeter by the end of the second month.

As the uterus becomes more and more distended its irritability becomes increased. At an early stage more or less regular waves of contraction pass over it. These may be increased by abdominal contraction or by emotions or by the movements of the fetus. It is only during the latter part of pregnancy that these movements produce any noticeable effect. They then produce a change in the position of the fetus, causing its occiput to occupy a position opposite the internal os. There also occurs a gradual softening of the cervix. As the uterus becomes more and more dilated there

is a dilatation of the upper portion of the cervix. It becomes drawn up upon the fetus. Not only does the musculature of the uterus undergo this great hypertrophy, but the vaginal walls become thickened and the round and broad ligaments of the uterus thicker and stronger.

Parturition—Finally when the dilatation of the os has reached a certain point, labor becomes precipitated, and the uterine contractions become strong and frequent enough to expel the fetus. The exact cause of the onset of labor is not thoroughly understood. It has been suggested that it depends upon the collection in the maternal blood of some substance which, during the previous days of its development, is consumed by the fetus. However this may be, labor can always be induced by a dilatation of the os.

In any case it must not be forgotten that the process of parturition involves a number of true reflexes acting through definite centers in the lumbo-sacral region. These centers send impulses not only to the uterus, but also to the diaphragm and abdominal muscles. A destruction of the lumbo-sacral region abolishes the power of parturition, whereas section of the spinal cord in the dorsal region does not do so.

Lactation—The maternal organism not only produces the embryo and provides for its housing and nourishment, and finally when it is able to live a separate existence expels it into the world, but it also provides for its nourishment for the first year of life, during a period when its digestive apparatus is unable to cope with any indifferent food which might be available.

During pregnancy there occurs a remarkable hypertrophy of the breasts of the mother. Actual secretion does not begin, as a rule, until the second or third day after birth. Secretion begins even if the child is born dead, but for the maintenance of secretion suckling is absolutely necessary.

The first secretion of the mammary gland is called colostrum. The colostrum differs from milk in containing little or no caseinogen. It contains in total 3% of proteins. These are lactalbumin and lactoglobulin. Colostrum is also rich in multinucleated cells containing fat globlets. There are probably in part leucocytes which have wandered into the acini, and in part the desquamated epithelium lining of the gland. The colostrum possesses a laxa-

tive effect on the child, thus enabling it to get rid of its collection of meconium.

The total amount of milk secreted increases from twenty grams on the first day to 211 grams on the third day, and then gradually up to 963 grams in the twenty-eighth week. After this in the average woman it diminishes in amount.

Milk—Milk of all animals possesses certain main features in common. Cow's milk may be taken as an illustration. It is an opaque fluid with sweet taste and characteristic odor. Its specific gravity varies from 1.028 to 1.034. It is neutral to litmus, and slightly alkaline to phenolphthalein. Its opaqueness is due to its rich content of fat drops. Its chief protein is caseinogen, a phosphoprotein. Treated with rennin the caseinogen is converted into paracasein which, in the presence of lime salts, is precipitated as casein. When a solution of caseinogen in the presence of lime salts is boiled, the caseinogen at the surface is coagulated as a pedicle. The sugar or carbohydrate of milk is lactose, and the salts are the salts of calcium, sodium and potassium, both the phosphates and chlorides, also magnesia and iron. It contains all the elements necessary to life, and not only so, but in proportions closely approximating the proportion of salts in the body of the young growing animal, which proportion often differs from that of the serum of the adult animal.

Practically every amino-acid or allied substance necessary for tissue building is present in casein. Moreover, there is a corresponding proportionality between the amount of lecithin in the central nervous system and that in milk. It must be remembered in this connection that lecithin is an abundant structural constituent of the central nervous system. These facts explain why it is undesirable to replace the milk of the mother of an animal with the milk of another species.

Cow's milk contains considerable more caseinogen than human milk, but less sugar. Human milk is also poorer in salts, especially the salts of calcium.

The following table shows the important differences:

		Proteins				
	Water	Caseinogen	Albumin	Fat	Sugar	Salts
Human milk..	88.5	1.2	0.5	3.3	6.0	0.2
Cow's milk...	87.1	3.02	0.53	3.7	4.8	0.7

Further than this the caseinogen of human milk gives certain different chemical reactions. It is easily precipitated by acids, and when coagulated by rennet does not form so firm a clot.

Milk from any species of animals may also contain antibodies against certain toxic agents or antigens to which the species may be immune. For this reason also an animal is best fed on the milk of its own species.

The Mammary Gland—Each mammary gland is composed of fifteen to twenty lobes containing numerous secreting tubules opening into ducts which pass to the nipple. The secretion of milk is essentially the formation of fat globlets in the epithelial cells lining the glands. Beside the fat droplets other granules are formed in the cells. These droplets are finally extruded into the lumen of the gland, but in this process there is an extensive degeneration of the cells themselves, so that in part the secretion is a process of desquamation of degenerated cells. The caseinogen and lactose are not formed by any other gland in the body than the mammary gland.

The Stimulus to Lactation—The problems suggested by the hypertrophy of the mammary gland during pregnancy, and the sudden onset of secretory activity at the birth of the infant, and the factors responsible for continued secretion are interesting problems and are not thoroughly understood. Unquestionably the hypertrophy of the gland during pregnancy depends upon a hormone, and it is assumed that this hormone is produced in the corpus luteum of the ovary or in the growing fetus. It is possible that the hormone is inhibitory in nature, or that another hormone inhibitory in nature to secretion is produced by the fetus, and that with the removal of the fetus this inhibiting hormone is removed and secretion begins. Another factor in the supply of fat for secretion is the absorption of the involution products in the uterine musculature.

Whether the influence of suckling in maintaining secretion acts solely by removing the secretory products, or in part by setting up reflex influences, the afferent impulses of which start in the nipple, is not known.

Another important function of suckling is its effect on involutions of the uterus. Putting the child to the breast excites uterine contractions and certainly stimulates the progress of normal in-

volution. No mother who neglects this duty fulfils her duty either to herself or to her child.

SUBSEQUENT GROWTH

The subsequent growth of the baby depends upon an impulse inherent in every cell, and controlled by both the nature of the food supplied and specific hormones produced in the body by a number of the ductless glands. Growth, however, will proceed quite independent of food supply. In an animal, on a diet which permits of no increase in weight, growth is nevertheless occurring. The relation between the size of the different parts of the animal by no means remains constant because there is merely no increase in weight.

For continuous growth to take place it is essential that the material out of which protoplasm constructs itself should be supplied. Not only must all the elements themselves be supplied, but properly combined in a manner capable of forming usable chemical or constructive units. In the absence of certain of these units, though all the necessary elements may be there, growth will not take place. Charts illustrate how the mere absence of a necessary amino-acid will affect the rate of growth.

QUESTIONS AND ANSWERS

Page 4

Q. What acquisition has been gained by the evolution of higher forms of life from the simpler forms?

A. The higher perfection of function through specialization.

Q. Define growth.

A. Growth is the continuous or interrupted increase in size of a living organism.

Page 6

✓ Q. Describe the ovary.

A. See text.

✓ Q. Describe ovulation.

A. See text.

Page 10

Q. Describe fertilization.

A. See text.

Page 14

Q. Describe the early stages of the development of the ovum.

A. See text.

Q. What is the chorion? Describe its development.

A. See text.

Page 18

Q. Describe the development of the three germinal layers.

A. See text.

Q. Describe the development of the cœlom and amnion.

A. See text.

Page 20

Q. Describe the development of the germinal layers of the embryonic area.

A. See text.

Page 22

Q. Describe the development of the primitive alimentary canal.

A. See text.

Page 24

Q. What is the allantois? Describe its development.

A. See text.

Page 26

Q. Describe the development of the nervous system.

A. See text.

Page 32

Q. Describe the differentiation of the mesoblast.

A. See text.

Page 36

Q. Describe the development of the face.

A. See text.

Page 40

Q. What are the branchial arches? Describe their development. What do they represent?

A. See text.

Page 46

Q. Describe the primitive form of the heart, the site of its development and the method by which it changes into the adult form.

A. See text.

Page 58

Q. Describe the development of the portal circulation of the liver.

A. See text.

Page 78

Q. From what embryonic structures do the various portions of the urogenital tract develop?

A. See text.

LECTURE NOTES ON PHYSIOLOGY

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RESPIRATION

THE LUNGS

DEFINITION OF RESPIRATION.

External and Internal Respiration—The oxygen for the needs of the body is taken in by a process of diffusion between the air and the blood. The latter transports it to the cells of tissues remote from the lungs. Here again, by another process of diffusion, it is given up to the tissues. The term external respiration has been applied to the intake of oxygen from the air of the outside atmosphere and internal respiration to the process of diffusion of oxygen to the tissues; only the latter is needed in the unicellular animal.

ANATOMY OF THE LUNGS AND PLEURAL CAVITIES.

The Anatomical Structure of the Lungs and their Adaption to the Function of External Respiration—The anatomical structure of the lungs affords every opportunity for rapid diffusion of gases. (Fig. 1.)

The external air is conducted to the lungs through the larynx and trachea—a tube about 4½ inches long. This divides into the right and left bronchi. Each of these subdivide and by repeated subdivision of the resulting bronchi, tubes of very small diameter are formed and penetrate the whole of the lung. (Fig. 2.) The walls of the larger bronchi contain cartilage which maintains their patency. (Fig. 3.)

The walls of the bronchioles, on the other hand, contain no cartilage, but possess a coat of smooth muscle fibers, by the extreme contraction of which their lumen may be actually obliterated. The smallest bronchioles open into slightly wider tubes, the infun-

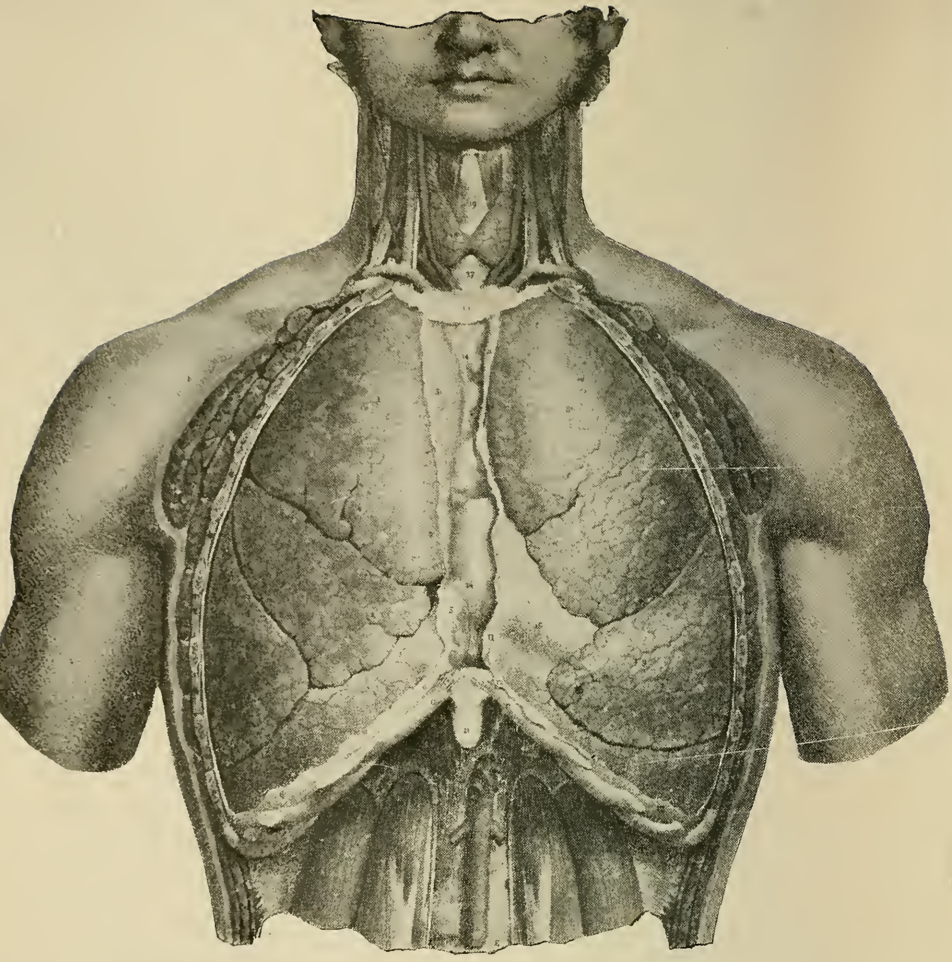

Fig. 1.—Illustrating the manner in which the lungs fill the chest cavity and their relation to the chest wall.

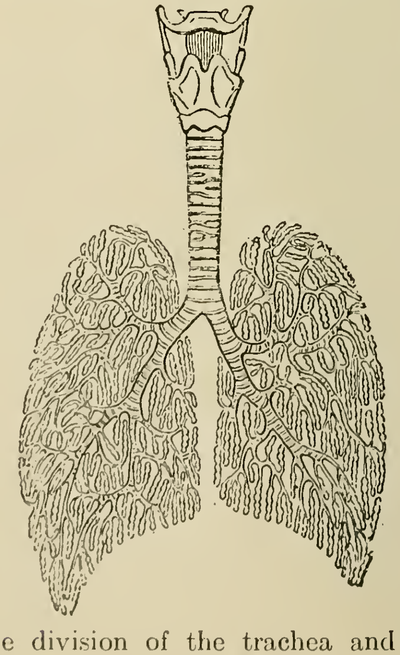

Fig. 2.—Illustrating the division of the trachea and the bronchi into their finest subdivisions.

dibula, in the walls of which are the openings of minute sacs, the alveoli of the lungs. (Figs. 5 and 6.)

The trachea, bronchi, and bronchioles are lined with ciliated columnar epithelium, the infundibula with a more cuboidal epi-

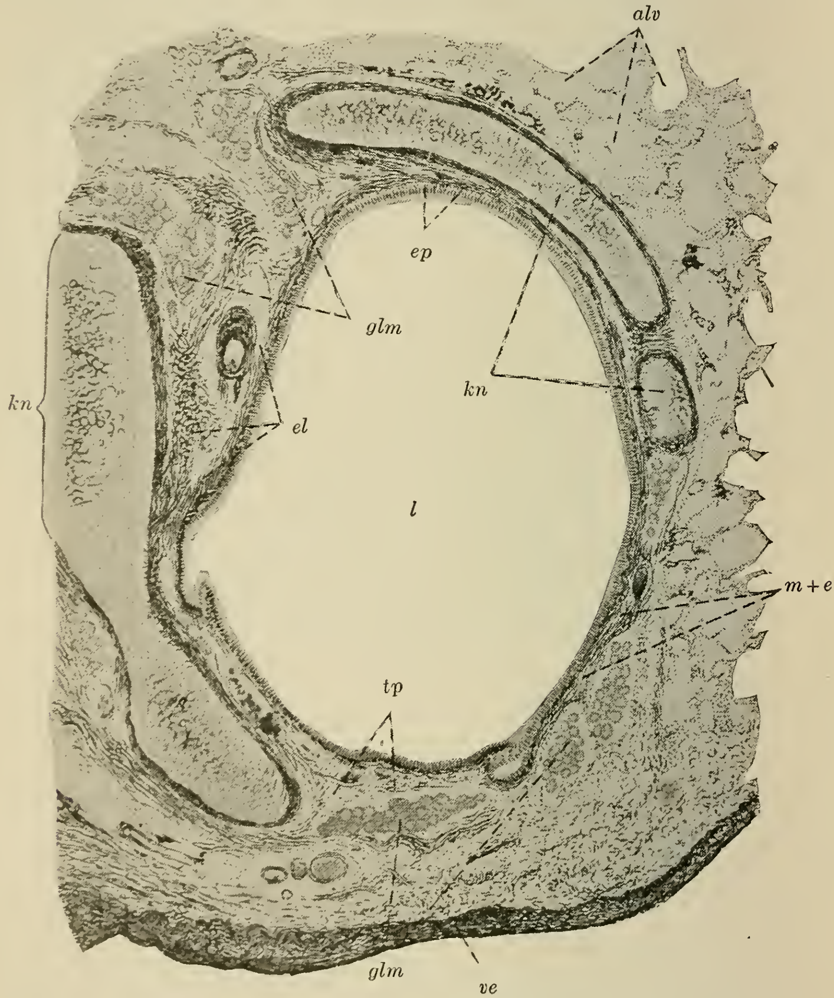

Fig. 3.—Cross section of one of the smaller subdivisions of a bronchus.
ep = epithelium.
glm = mucous glands.
tp = tunica propria.
kn = cartilage.
l = lumen.
ve = veins.
m + e = smooth muscle and elastic fiber.
alv = alveoli in the vicinity.

thelium, while the alveoli are lined with very flat squamous cells. Immediately external to this thin layer of squamous cells is a rich capillary network. (Figs. 6 and 7.)

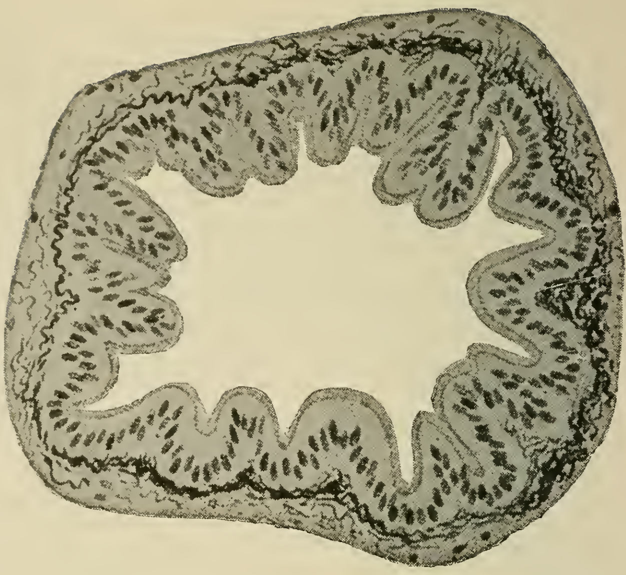

Fig. 4.—Transverse section through small bronchus of human lung. (Sobotta.) Simple columnar ciliated epithelium; no cartilage; no glands; mucosa folded longitudinally; elastic tissue stained with Weigert's elastic tissue stain.

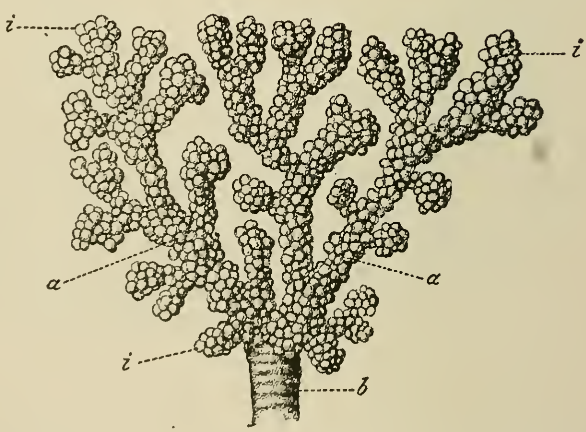

Fig. 5.—From lung of an ape. The bronchi and their dependent ducts and alveoli have been filled with quicksilver. X 15. (Kölliker.) *b,* terminal bronchus; *a,* alveolar duct; *i,* alveoli.

The amount of connective tissue, forming in other regions of the body a basement membrane, and participating in the formation of a lymph space around the capillary network, is reduced to a

Fig. 6.—Section of lung of a rat to show arrangement of bronchial ramifications and of alveoli within a single lobule.

bl = lobular or sublobular bronchus.
bil = intralobular bronchus.
ba = terminal bronchus.
v = dilatation sometimes called vestibule.
ca = alveolar canal.
i = portion sometimes called infundibulum.
d = alveoli, some of which are so cut as to show their openings into the infundibulum and alveolar canals while others appear closed.

minimum in the lungs, so that practically the blood within the capillaries is separated from the air in the alveoli by a single layer of endothelium and a layer of epithelial cells of extreme thinness. The alveoli of the lungs are closely set together, so that adjacent

alveoli appear separated by a single partition; actually a single capillary network is placed in the partition between two adjacent alveoli.

The Development of the Lungs—The lungs develop by a sac-like bud from the anterior wall of the primitive alimentary canal.

By the growth of this sac, which we may term a primitive alveolus, the two lungs become formed and fill the thoracic cavity.

The Pleural Cavity—The outer surface of the lungs remains

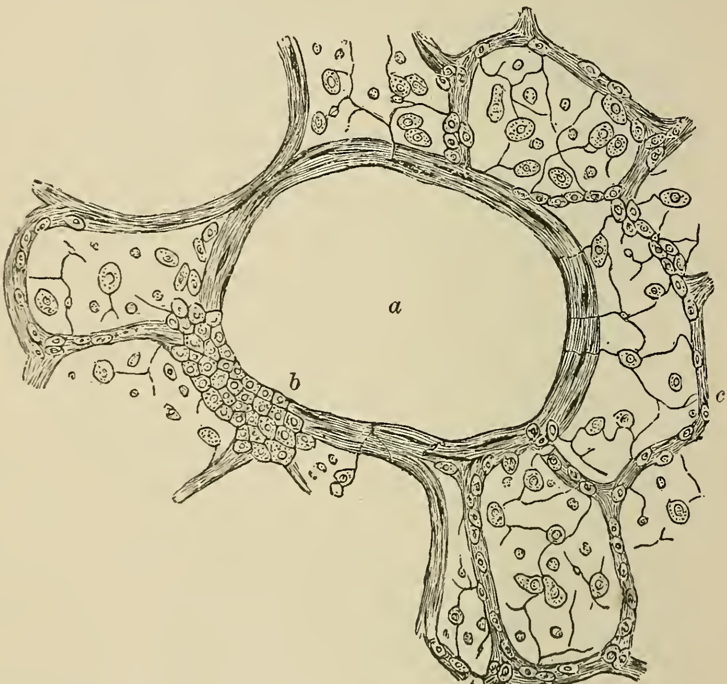

Fig. 7.—From section of a cat's lung stained with silver nitrate. Small bronchus surrounded by alveoli in which are seen flat cells (respiratory epithelium) and cuboidal cells (fœtal cells).

constantly separated from the internal surface of the chest wall by a permanent opening of the pleural cavity. The continued patency of this cavity is maintained by the fact that the cavity forms between two layers of endothelial cells. One layer covering the lung is the visceral pleura, and the other layer covering the internal surface of the thoracic wall is the costal pleura. Thus a flattened bag composed of a single layer of endothelial cells, covering and attached to the lung on the one side and covering and attached to the chest wall on the other side, is interposed between the lung and the chest wall. The opposed surfaces of this bag are kept moistened

by lymph, so that their surfaces glide over each other easily during the movements of the lung.

PHYSIOLOGY OF RESPIRATION.

The Mechanism Causing the Lungs to Follow the Movements of the Thoracic Walls—Inasmuch as the pleural bag or cavity is a flattened one, the two surfaces being in contact for practically their whole extent, any enlargement of the thoracic cavity by a movement of its walls outward (*i.e.*, away from the center of this cavity) will cause the lungs to dilate in order to follow this movement of the walls of the thorax. Any tendency on the part of the lungs to resist such an enlargement causes a corresponding diminution of the atmospheric pressure within the pleural cavity. The lung tissue between the alveoli and bronchi contains elastic tissue

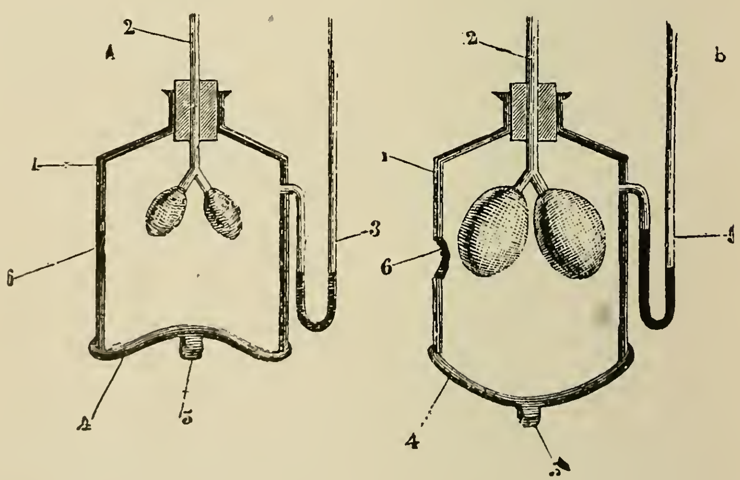

Fig. 8.—Illustrating the forces which control the expansion and deflation of the lungs, elastic organs inclosed within a cavity, the walls of which are unyielding except around the cavity at 6, where elastic provision exists for elongation or enlargement of the space surrounding these elastic bags. Upon enlargement of the space there is a diminution of the air pressure indicated by the manometer 3. This causes the air of the external atmosphere to rush in to the elastic bags and distend them.

which tends to contract when put on a stretch. Consequently when the lung is pulled out, so to speak, by the movement outward of the chest walls, the elasticity of these fibers resists the dilatation of the lungs, causing a diminution of the atmospheric pressure in the pleural cavity. As soon as the muscles (*i.e.*, the

intercostal muscles and the diaphragm) concerned in this enlargement of the thoracic cavity cease acting, the contraction of these elastic fibers becomes efficient and the lung diminishes in size. The weight of the chest walls in the relaxed condition of the intercostal muscles and the intra-abdominal pressure pressing the diaphragm upward, both aid in the retraction of the lung. The enlargement of the lung with the enlargement of the chest wall could not occur unless it were possible for the pulmonary alveoli to dilate easily. The whole mechanism is made clear by reference to the artificial model illustrated in Fig. 8.

The communication of the alveoli through the bronchi and trachea with the external atmosphere makes it possible for air to rush into them and thus permit of their easy enlargement unopposed by the creation of a vacuum in their interior. In the same manner when the muscles of the thoracic walls relax the diminution of the cavity of each individual alveolus is unopposed because its contained air easily rushes out again into the bronchi and trachea. Thus it is by the alternate enlargement and diminution of the cavity of the thorax that a continued renewal of the air in the alveoli of the lungs takes place.

This alternate enlargement and diminution of the thoracic cavity is accomplished by the respiratory muscles and the whole process is called respiration.

The filling of the lungs, accomplished by the contraction of the muscles of respiration, is called inspiration, and the retraction of the lungs with the expulsion of the air is called expiration.

At the end of expiration there is a slight pause.

The Rate of Respiration—The respiratory movements are repeated in the normal adult about 10-18 times a minute, in the newborn child 44 times a minute and in the child of five years about 26 times.

Respiration is much affected by psychical influences. It is also very greatly under the control of the will; but while it is possible to breathe rapidly or slowly, it is not possible to cease breathing indefinitely.

The Muscular Mechanism of Respiration—The principal muscles of respiration are the diaphragm, the muscles of the abdominal wall, and the intercostal muscles.

The Diaphragm—The diaphragm forms a large sheet of muscu-

lar fibers and a central tendinous portion which together separate the contents of the thorax from the abdomen. It may be considered as arising from an anterior and a posterior origin, and as inserted into its own central tendon. The anterior origin arises in front from the posterior surface of the xyphoid cartilage and lower border and inner surface of the costal cartilages of the six lower ribs, sometimes also from the anterior extremity of these ribs.

The posterior origin is from the ligamentum arcuatum externum, stretching from the tip of the transverse process of the second lumbar vertebra to the tip of the twelfth rib; from the ligamentum arcuatum internum stretching from the body of the second lumbar vertebra to the tip of its transverse process; and from the right and left crura of the diaphragm. These last are two strong muscular bundles arising on the right side from the anterior common ligament and front of the bodies of the third or fourth lumbar vertebra and on the left side from the bodies of the first to the third vertebra and the anterior common ligament in front of them. From this extensive origin, completely surrounding the transverse section of the body, the fibers of the diaphragm pass upward and internally to be inserted into its central tendon. Beneath each lung the diaphragm forms a cupola.

Movements of the Diaphragm during Respiration—It is the cupola which rises and falls during respiration, the central tendon moving very little during respiration.

To the upper surface of the central tendon the pericardium is attached, and this portion moves but little during respiration.

Toward the posterior portion of the area to which the pericardium is attached a little to the right of the middle line, the central tendon is pierced by the inferior vena cava. This portion of the central tendon does not move at all during respiration. As the periphery of the central tendon is approached its movement during respiration becomes greater.

The cupolæ perform the greatest excursions. They amount to about half an inch during quiet respiration. Beneath the cupola on the right side is the liver, and beneath that of the left side is the stomach and spleen. (Fig. 9.)

The Part Played by the Abdominal Muscles and by Inhibition during Respiration—During expiration these organs are pressed by the abdominal muscles up against the diaphragm. During in-

Fig. 9.—Diagram showing movements of diaphragm in respiration. (Yes.)
ii = inspiratory position of the cupolæ.
ee = expiratory position of the cupolæ.

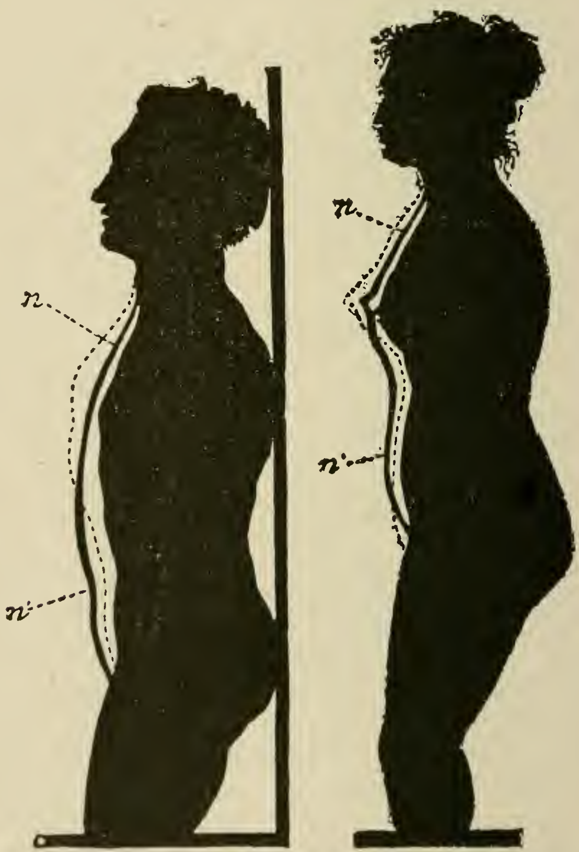

Fig. 10.—Diagram illustrating the variation produced in the anteroposterior diameter of the thorax and abdomen in the two sexes by normal respiration (the heavy line) and forced inspiration (dotted line). The diagram also illustrates the relative part in respiration taken by thoracic and abdominal breathing under normal and forced conditions.

spiration the abdominal muscles are relaxed by inhibitory impulses which form part of the central nervous mechanism controlling respiration and responsible for its involuntary automatic maintenance. The important part played by the abdominal muscles in respiration is illustrated when these muscles are relaxed and flabby, as in the conditions known as ptosis and rachitis. In these conditions respiration is performed by the upper part of the thorax. There is comparatively little abdominal or diaphragmatic breathing in these conditions. (Fig. 10.)

Forces Resisting the Displacement of the Origin of the Diaphragm—When the diaphragm contracts its effectiveness in depressing the dome beneath each pleural cavity is greatly increased by forces which render fixed its origin around the periphery of the body. These forces not only render its attachment around the periphery of the body fixed but resist the inwardly directed tension of the diaphragm by an actual movement of the peripheral origin of the diaphragm outward. During inspiration there is a contraction of the quadratus lumborum muscle, pulling the lower rib backwards and downwards, and of the external intercostal muscles causing adjacent ribs to collide in such a manner that an upper one moves forwards in relation to the one below it. The lower borders of the ribs are at the same time everted.

The Part Played in Respiration by the Abdominal Muscles—The intra-abdominal pressure is also a factor in restoring the relaxed diaphragm to its normal position during expiration. Even during inspiration the tone of the abdominal muscles is not entirely relaxed and by this partially maintained tone they oppose the contraction of the diaphragm during inspiration and so keep the abdominal viscera pressed up against the under surface of the diaphragm and in this way assist in the spread of this muscle during its contraction. The part played in inspiration by the intra-abdominal pressure is well emphasized by the deep groove appearing around the body at the level of the origin of the diaphragm in children with rachitis and weak, flabby abdominal muscles and by the more thoracic character or respiration in adults with poorly developed abdominal muscles. The contraction of the diaphragm lasts four to eight times longer than a single twitch in other muscles. It is a short tetanus.

The Enlargement of the Chest in an Upward, Forward and Outward Direction—So much for the enlargement of the thorax

during inspiration in a downward direction; but the chest also enlarges by a movement of the ribs forward and upward, and outward and upward. Each rib articulates posteriorly by its head with the body of the vertebra and a short distance external to the head with the tip of the transverse process of the vertebra. The axis of the rib between these two points is directed horizontally outward, but beyond the articulation of the rib with the transverse process the rib begins to curve forward and the angle of the rib represents a sharp turn forward and downward. The curve is continued until the chest cavity is surrounded and the curve becomes a forward and inward one to the juncture of the rib with the costal cartilage.

The Part Played by the Costal Cartilages—The costal cartilages unite the anterior extremity of the ribs with the sternum.

They pass sharply upward and inward, the lower cartilages passing more steeply upward than the upper ones. Because of their direct attachment to the ends of the ribs and their elasticity they resist the upward movement of the ribs during inspiration and assist in the return of the ribs during expiration.

The Part Played by the External Intercostal Muscles—The direction of the ribs downward and forward is an important factor in the enlargement of the chest in an upward direction during inspiration. By a contraction of the external intercostal muscles which pass between the ribs in a downward and forward direction, any point of attachment of the external intercostal muscle along the upper border of one rib is made to move backward in its relation to the attachment of these same fibers along the lower border of the rib above. Such a telescopic or colliding movement, so to speak, the whole of the first rib and the posterior extremity of all the other ribs being fixed, cannot occur without the ribs rotating around both an anterior posterior axis passing through the head of the rib behind and the costal cartilage near the anterior extremity of the rib in front and a transverse axis corresponding to the long axis of the neck. Such a movement causes the thoracic cavity to enlarge in virtue of three effects produced upon the rib: (Figs. 11 and 12.)

1. The anterior extremities of the ribs are elevated and, inasmuch as the lower ribs are longer than the upper ones, the sternum is lifted upward and forward.

2. In rotating around the anteroposterior axis before mentioned the lateral portions of the ribs and, therefore, the chest wall move upward and outward.

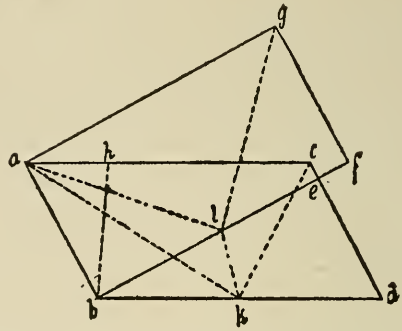

Fig. 11.—Scheme demonstrating the antagonistic function of the external and internal intercostal muscles.

3. Inasmuch as the outer surfaces of the ribs in a position of repose look downward and outward, and the rotation around their anteroposterior axis causes the outer surface to look a little

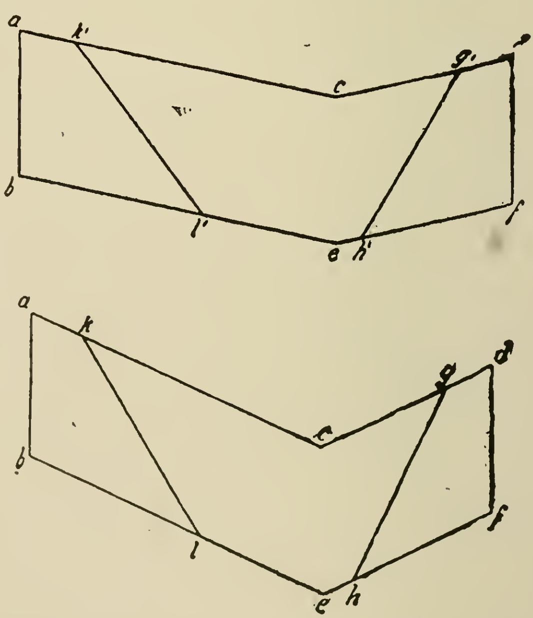

Fig. 12.—Scheme demonstrating the function of intercartilaginous portion of the internal intercostal is the same as the interosseous portion of the external intercostal muscle.

upward and outward, there occurs, so to speak, a true eversion of the lower border of each rib.

The Accessory Muscles of Respiration—During forced inspira-

tion other muscles are brought into play. These are called the accessory muscles of respiration. It is possible that some of them, by fixing the uppermost ring of the thorax, should be considered muscles of normal respiration. They are:

1. Erector spinæ and its continuation upward into the other muscles which straighten the spine.
2. The scaleni.
3. Sternomastoid.
4. Trapezius.
5. Pectoral muscles.
6. Rhomboids.
7. Serratus anticus.

The Forces Causing Expiration—Normal expiration is accomplished chiefly by the relaxation of the muscles of inspiration and the elasticity of the costal cartilages and the lung tissue. The weight of the chest walls falling over the lungs during the period of relaxation of the muscles of inspiration is an important factor in expiration.

Unquestionably the internal intercostal muscles must be classed with the expiratory muscles. Their fibers pass downward and backward, and when they contract they will produce just the opposite movement of the adjacent borders of two ribs in their relation to each other to that which is produced by this contraction of the external intercostal muscles.

There will, therefore, be a return of the ribs to their former position.

The Movements of the Lungs During Respiration in Relation to the Chest Wall—The enlargement of the thorax causes the lung to follow the movement in those directions in which the chest wall moves. Chiefly the outer and lower surfaces and anterior borders of the lungs move during respiration. Those portions in contact with the immovable boundaries of the thoracic cavity, the spinal column behind, the mediastinal surfaces in contact with each other, and the other important structures within the mediastinum and the apices of the lung in contact with the deep cervical fascia, move very little during respiration, and not at all in a direction away from the center of the lung.

The margins of the lung are not quite the same as the boundaries of the thorax.

The apices extend about one inch above the clavicle, anteriorly and behind are on a level with the seventh spinous process.

At the end of a moderate expiration the lower border of the lungs passes from the upper border of the sixth rib at its insertion into the sternum downward and backward to the tenth rib, at the back of the chest.

During the deepest inspiration the lower border descends to a line passing from the seventh intercostal space in front to the eleventh rib behind.

In the front of the chest there is always a small triangular space uncovered by lung tissue. This space extends to the left border of the sternum on the right, above to the fourth right sterno-costal articulation and below to the sixth costal cartilage as far out as the position of the apex beat of the heart. The size of this space varies during respiration.

Breath Sounds—Under normal conditions a fine rustling sound may be heard by placing the ear close to the chest during respiration. It is produced by the air rushing through the more narrow infundibula. It is termed vesicular breathing. At the back of chest, internal to the spine of the scapulæ at the level of the fourth dorsal vertebra the sound is louder and deeper in quality, resembling a whispered *ha!* This change in quality is due to the proximity at this place of the large bronchi, and the sound has the same quality as the still louder but similar sound heard by placing the stethoscope over the trachea or larynx.

When the lung is solid, as in pneumonia, this sound is transmitted by the solid exudate, so that it is heard all over the whole chest.

Intrapleural Pressures during Expiration and Inspiration—The lungs never completely fill the thoracic cavity except in the newborn mammal. Consequently a negative pressure, determined by the elasticity of the lungs, exists within the thoracic cavity even at the end of expiration. The varying degrees of negative intrathoracic pressure may be recorded by placing the pleural cavity in series with a mercurial manometer. The intrathoracic pressure will be highest just before the end of inspiration, and lowest at the beginning of expiration. The elasticity of the lungs exerts normally a tension equalling —6 m.m. of mercury. This may be considered to represent the average intrapleural negative

pressure during inspiration. It may be increased during forced inspiration to -30 m.m.

Intrabronchial Pressures—Within the larger air passages, the nasal cavities, and the trachea, there is a negative pressure of -1 m.m. of mercury during inspiration and a positive pressure of $+2$ to $+3$ m.m. of mercury during expiration.

During forced inspiration and expiration the pressure may be -57 m.m. and $+87$ m.m. respectively.

The Movements of the Vocal Cords During Respiration—Accompanying quiet breathing there is a rhythmical movement of the vocal cords. During inspiration they separate and become approximated during expiration.

QUANTITIES OF AIR INTERCHANGED DURING RESPIRATION

Measured dry and at 0° C. about 500 c.c. of air are breathed in and out at each respiration. At the body temperature, 37° C., this amount will measure 600 c.c. It is called the tidal air.

At the end of a normal inspiration of quiet breathing an additional 1500 c.c. of air may be inspired by a forced effort. This additional amount is called the complemental air. In the same manner at the end of a normal expiration of quiet breathing an extra quantity of 1500 c.c. may be still forced out of the lungs. This quantity is called the supplemental air.

After the supplemental air has been forced out of the lungs about 600 to 1200 c.c. still remain in the lungs. This is called the residual air.

About 140 c.c. of air fill the air tubes so that only 360 c.c. of the tidal air reaches the alveoli. Expired air, therefore, consists of the air (140 c.c.) within the large tubes, the trachea and bronchi, the so-called "dead space," diluted with the 360 c.c. from the alveoli, the so-called alveolar air.

THE REGULATION OF RESPIRATION.

It is the chief function of respiration to eliminate carbon dioxide from the blood and to maintain a sufficient quantity of oxygen within the pulmonary alveoli to enable the red blood cells to pick up a sufficient quantity for the needs of the tissues.

The Relative Amount of Carbon Dioxide Eliminated and Oxygen Taken in—An adult man during twenty-four hours produces on the average 250 c.c. of carbon dioxide per hour per kilo of body weight. A man of 60 kilos, therefore, will excrete 360,000 c.c. of carbon dioxide in twenty-four hours. The amount excreted per hour varies from 160 c.c. during sleep to 295 c.c. during waking hours. All this carbon dioxide represents the ex-

penditure of a definite amount of energy, which only occurs through the process of oxidation, and, therefore, represents the consumption of a definite quantity of oxygen. The amount of oxygen taken into the body bears, therefore, a definite relation to the amount of carbon dioxide excreted, but not all the oxygen is taken in by inspiration. The three classes of foodstuffs which are oxidized to supply the energy needs of the body contain some oxygen, and each a different proportion.

Therefore, according to which class of foodstuff is being used to supply the energy needs of the body, the relation of the carbon dioxide excreted to the oxygen inspired will vary somewhat. This relation is called the respiratory quotient, and is expressed by the fraction the *amount of* CO_2 *excreted over the amount of* O_2 *inspired*. The average value of this fraction is 0.85. By the use of this fraction the amount of oxygen inspired may be calculated from the amount of carbon dioxide excreted. By so calculating it the amount of oxygen inspired will equal 347 c.c. per kilo per hour while the subject is awake. If a man breathes 17 times a minute, and the tidal air amounts to 500 c.c., the total pulmonary ventilation will be $500 \times 17 \times 60 = 510{,}000$ c.c. per hour. If this air contains 300 c.c. of carbon dioxide per kilo per hour, and therefore 300×70 for a man of 70 kilo or 21,000 c.c. of carbon dioxide, the expired air contains 4.1 per cent. of carbon dioxide and by the same method of calculation 16.4 per cent. of oxygen.

The composition of inspired air at 0° C. and 760 m.m. pressure is:—

Oxygen	20.96 vols. per cent.
Nitrogen and argon	79.00 " " "
Carbon dioxide	0.04 " " "

Of expired air is

Oxygen	16.4 vols. per cent.
Nitrogen	79.5 " " "
Carbon dioxide	4.1 " " "

Expired air measures a little less than inspired air because of the disappearance of some of the oxygen without a corresponding increase in the amount of carbon dioxide.

The amount of moisture in inspired air rises with the time of

year. Expired air is approximately fully saturated with water vapor. The tension of this water vapor amounts to 50 m.m. of Hg. Therefore, if dry air is inspired possessing the tension of one atmosphere, or 760 m.m., the tension of the contained gases within the alveoli will only amount to 760-50, or 710 m.m. of mercury.

The percentages of gases contained in expired air given above refer to the percentages in the alveolar air. The expired air of the mouth represents alveolar air diluted with the amount of air necessary to fill the trachea and bronchi. This amount is 140 c.c. In other words, of the normal quantity of tidal air breathed only 360 c.c. reaches the alveoli. Therefore the expired air at the mouth only contains about 3 per cent. of carbon dioxide. The changes in the alveolar air which are produced by respiration are by no means so marked as are those produced in the tidal air. In fact, it becomes a matter of importance, as has been explained, that the alveolar air should have a uniform composition, and that a sensitive mechanism for keeping it should exist, for entirely upon the composition of the alveolar air will depend the quantity of CO_2 and oxygen within the blood.

The Factor Immediately Determining the Quantity of Carbon Dioxide and Oxygen in the Blood—The blood leaving the lungs contains much less carbon dioxide and more oxygen than that coming to the lungs. The amount of carbon dioxide lost and oxygen gained by the blood in its passage through the lungs will depend entirely upon the percentages of carbon dioxide and oxygen in the air of the alveoli. These percentages will in turn depend upon the rapidity with which the air in alveoli is changed, and this rapidity directly upon the frequency of respiration. Unless, therefore, the rate and depth of respiration is varied according to the body's variations in the consumption of oxygen and production of carbon dioxide, constant percentages of oxygen and carbon dioxide in the blood will not be maintained.

The Necessity for the Existence of a Uniform Quantity of Carbon Dioxide in the Blood—Inasmuch as serious disturbances arise from a deficiency of oxygen or from either a deficiency or excess of carbon dioxide in the blood it becomes a matter of importance that the body should maintain a constant proportion of these gases in the blood.

As, however, the production of carbon dioxide always bears a

nearly uniform ratio to the amount of oxygen taken in, and inasmuch as the composition of the atmosphere in regions ordinarily frequented by man is approximately constant, it is only necessary that a mechanism should exist which is sensitive to variations in the proportion of one of these gases in the blood.

The respiratory mechanism does not respond to differences in the proportion of oxygen in the blood but only to a diminution or increase in the proportion of carbon dioxide. It is, however, extremely sensitive to changes in the amount of this gas in the blood, and it is owing chiefly to this fact that the proportion of both oxygen and carbon dioxide in the alveolar air and therefore in the blood are kept nearly constant. (Figs. 29, 30 and 31.)

The Necessity for Central Control—Respiration is accomplished only by the coördinated contraction and relaxation of a good many widely separated muscles; not only must certain of these muscles contract together or in proper sequence with each other, but synchronously with these contractions there must be a relaxation of other muscles.

The preservation of such a sequence of events with provision for variations in its rhythm in response to both chemical changes in the blood and nervous impulses from distant portions of the body can be maintained only by the existence of some center capable of activating all the muscles of respiration with motor and inhibitory impulses discharged in a proper coördinated sequence from it.

Such a center would form a common meeting place in which all influences affecting respiration could arrive and from which the combined effect of all these influences could not only vary the rhythm of respiration, but also maintain this rhythm by discharge impulses producing coördinated respiratory acts, because the discharging impulses would all come from one place, which is so connected with the various respiratory muscles that whenever the center is stimulated, either chemically (by CO_2) or reflexly, each muscle contracts or relaxes in its proper sequence and with a proper force.

Site of the Respiratory Center—By severing the various nerves associated with respiration and the spinal cord at different levels it is possible to determine the situation of the center controlling respiration.

A division of the spinal cord at the level of the first dorsal nerve, that is, below the origin of the phrenic nerves, causes all intercostal respiration to cease.

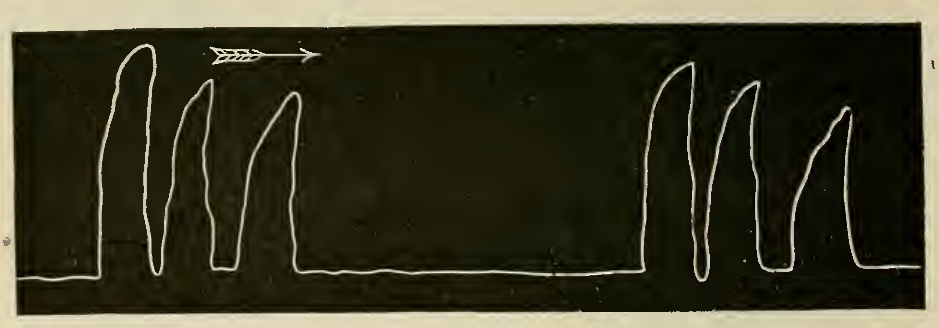

Fig. 13.—Irregular respiration in the rabbit after a horizontal division of the medulla at the level of the ala cinerea. The tracings are made from a slip of the diaphragm muscle and each ascending line represents a contraction of the diaphragm. (M. Marckwald.)

If the spinal cord is divided at the level of the second cervical nerve, both intercostal respiration and thoracic or diaphragmatic respiration cease. If, however, the brain stem is divided just above the medulla, or even through the medulla at the level of the

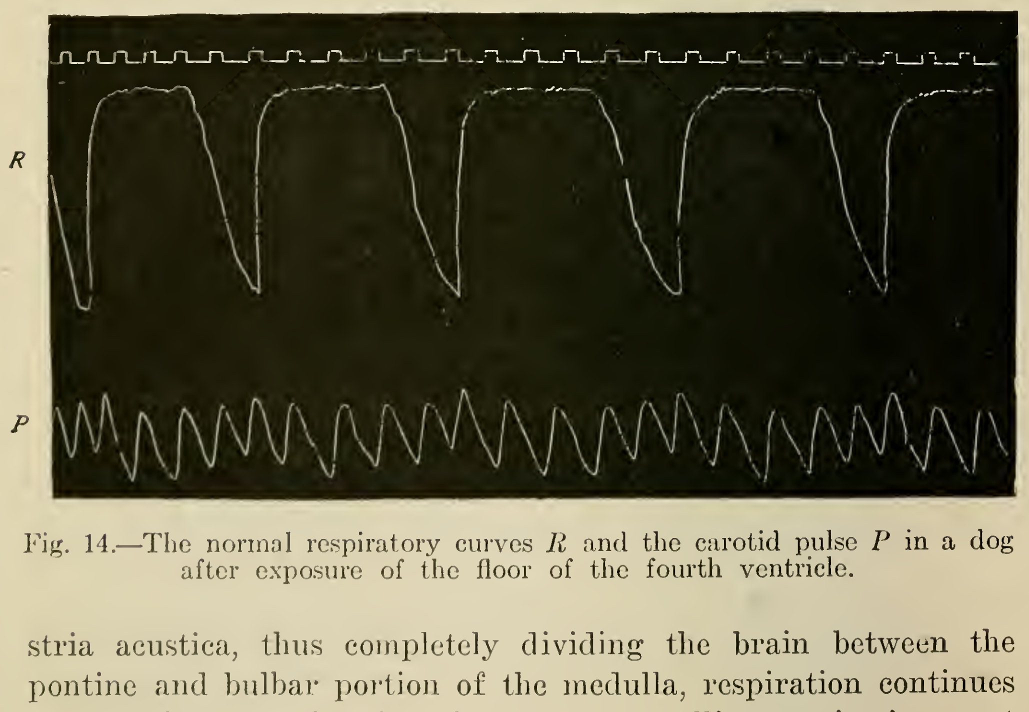

Fig. 14.—The normal respiratory curves R and the carotid pulse P in a dog after exposure of the floor of the fourth ventricle.

stria acustica, thus completely dividing the brain between the pontine and bulbar portion of the medulla, respiration continues without change. Therefore the center controlling respiration must

be located in the bulbar portion of the medulla. (Figs. 13, 14, 15 and 16.)

Attempts to more accurately locate the respiratory center in the

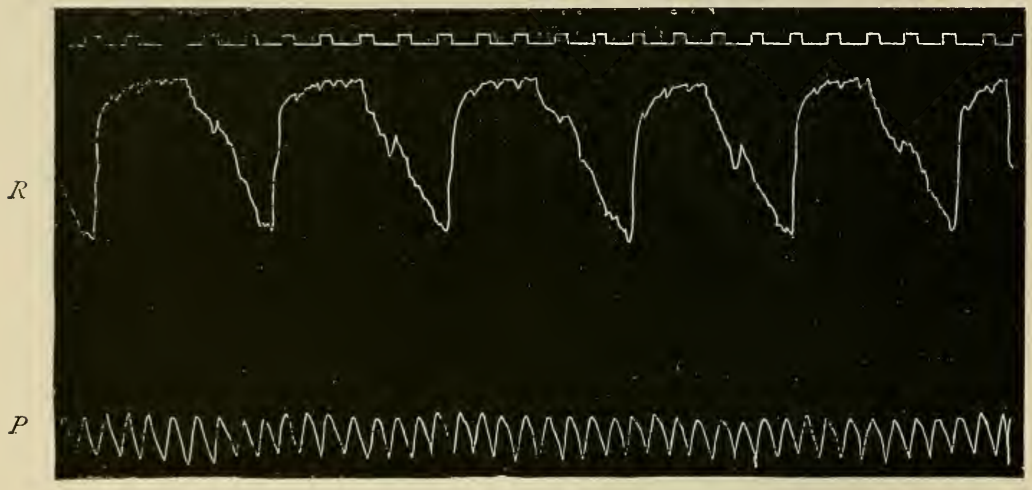

Fig. 15.—The same dog from which the preceding tracing was made. This tracing was taken 1 minute after the application of cocaine to the floor of the fourth ventricle.

floor of the very apex of the fourth ventricle, namely, the calamus scriptorius, have not been supported by more recent work. Apparently the cells belonging to this center are scattered over quite

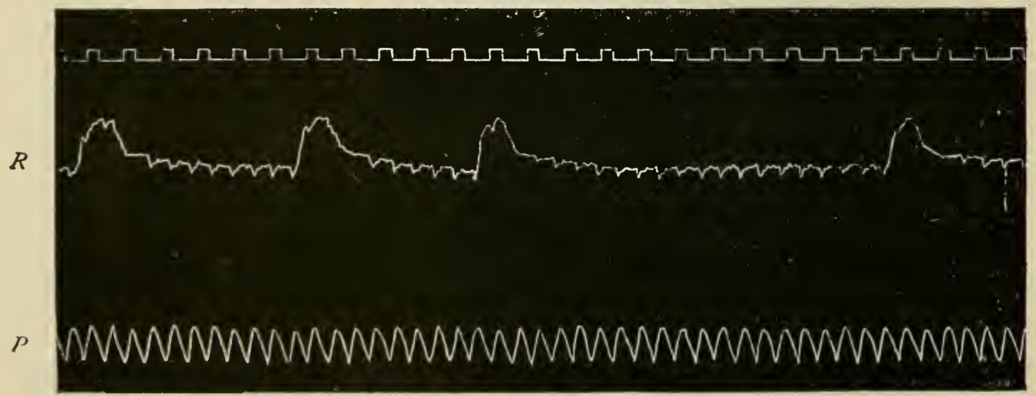

Fig. 16.—The same dog from which the two preceding tracings were made. This tracing was taken 9 minutes after the administration of the poison. In the curve *R* the expirations are active and inspiration passive. Later there was a complete cessation of respiration.

a large area, including many cells in which the vagus nerve ends connected with the folliculus solitarius, and cells scattered over a considerable portion of the formatio reticularis.

The Efferent Paths from the Respiratory Center—The axons from these cells pass down to cells in the spinal cord from which fibers pass to the respiratory muscles.

There must also exist communicating fibers connecting the cells of one side of the center with those in the cord of the opposite side, because afferent impulses from one side of the body stimulate the respiratory muscles on both sides. Probably connections between the two sides of the cord also exist. Nevertheless, in the

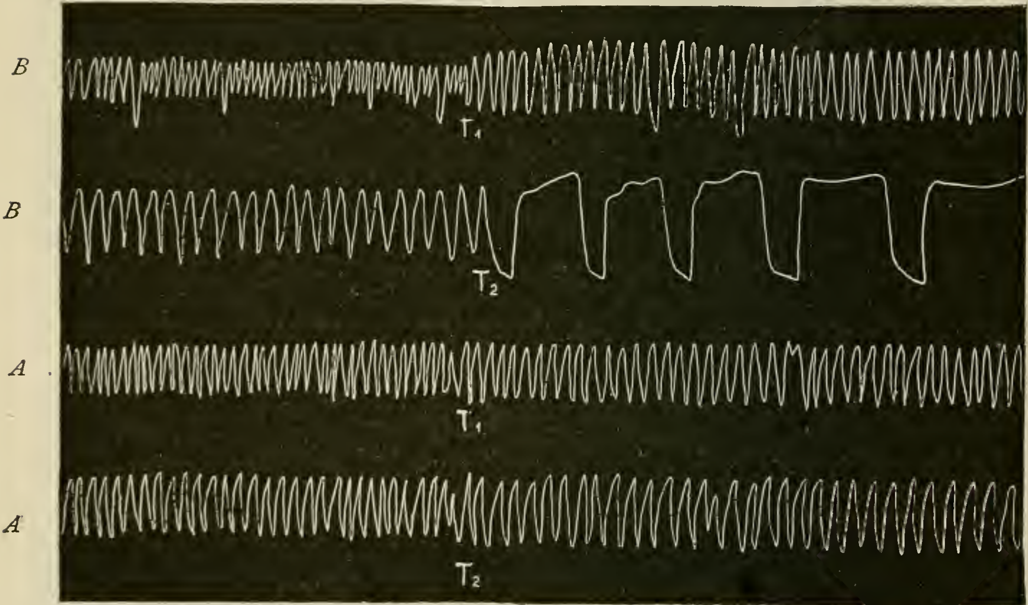

Fig. 17.—The effect upon the respiration of a division of the vagus nerve in the rabbit A A and dog B B. At T_1 the right vagus of each animal was divided and at T_2 the left was divided. As soon as the respiratory center misses the afferent impulses through the vagus, respiration becomes slower and deeper.

cord the functions of the two sides are sufficiently well separated to permit of unilateral respiratory movements after hemisection of the opposite side of the cervical portion of the spinal cord. The respiratory center discharges its impulses through nerve fibers passing down into the spinal cord.

The Afferent Paths and the Effect Produced by their Central Stimulation—Through what paths do the afferent impulses affecting the center pass to it? Secondly, without any such afferent impulses is the center capable of maintaining any activity at all? In other words, is the center automatic?

The afferent paths to the respiratory center may be traced in the same manner as the efferent paths have been followed. The respiratory center may be stimulated by afferent stimulation of many sensory nerves. The most important nerve connected with the bulbar portion of the medulla is the vagus nerve. A division

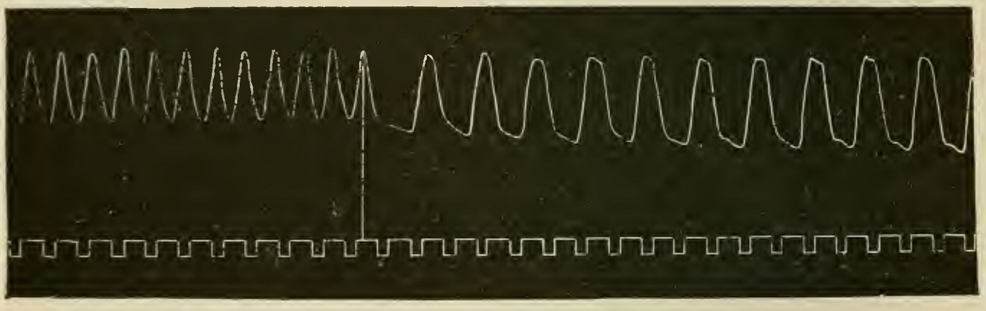

Fig. 18.—Illustrating the effect on the respiratory rhythm of suddenly rendering the vagi non-conductive by freezing. The moment of freezing of both vagi is indicated by the vertical line and the time marked in seconds below. When the respiratory center misses the vagal impulses the respiratory rhythm is slower and deeper.

or freezing of both vagi nerves results in a temporary increase of depth of inspiration, followed by a diminution in the frequency but increase in the amplitude of inspiration and expiration. (Figs. 17 and 18.) If the central end of one of the divided vagi is stimulated with an interrupted current the respiratory movements

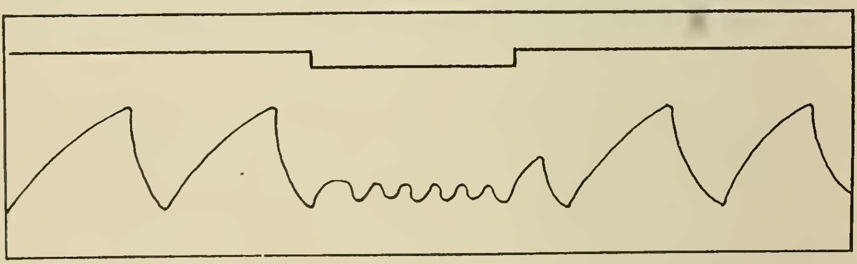

Fig. 19.—Stimulation of the central end of the vagus. Downstroke inspiration. During stimulation the chest remains partially filled in the inspiratory phase.

are quickened at the expense of expiration, so that finally a condition of inspiratory standstill may be reached. (Fig. 19.)

Weak stimulation of the central end of the vagus with an interrupted current will sometimes result in an increase of the expiratory movements at the expense of inspiration (Fig. 20); in

fact, the effect may represent entirely an inhibition of inspiration. These varying effects may follow the application of a constant cur-

Fig. 20.—Effect of stimulation of the central end of the divided right pneumogastric in a rabbit with a weaker current. There is an acceleration of the respiratory movements and a diminution of their amplitude. Up stroke indicates inspiration. The tracing is made by the method of P. Bert.

rent. (Figs. 21 and 22.) The vagus, therefore, must contain two sets of fibers. Important fibers carrying inhibitory impulses on in-

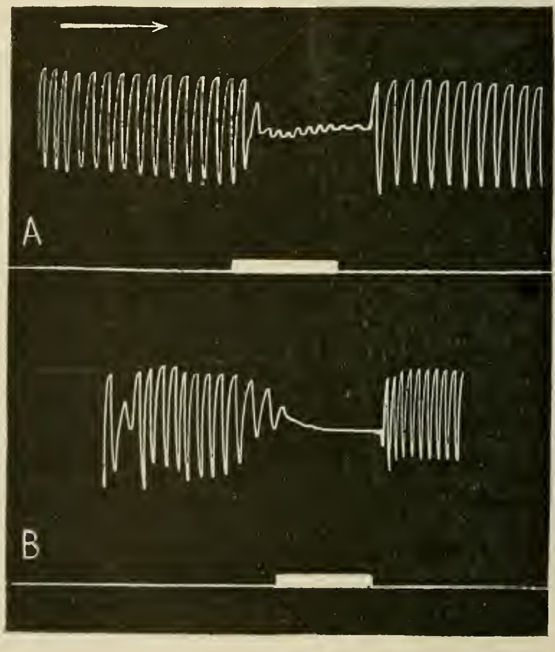

Fig. 21.—Strong stimulation in a rabbit by an induced current of the central end of the right pneumogastric. In both instances (in B the effect is more complete) there is an arrest of respiration in the inspiratory phase. The tracing is made by the method of P. Bert.

spiration and augmentatory impulses on expiration are contained in the superior laryngeal nerve. Central stimulation of this nerve

produces inhibition of inspiration followed by a forcible expiration (cough).

Summary of the Afferent Impulses Carried by the Vagus Nerve to the Respiratory Center—The vagus nerve, therefore, carries afferent fibers with two kinds of central connections—one set carries impulses which stop inspiration and augment or stop inhibition of expiration, and the other set impulses which inhibit expiration and increase inspiration.

These two sets of fibers are constantly utilized in the body to produce effects upon the respiratory center. The reality of this

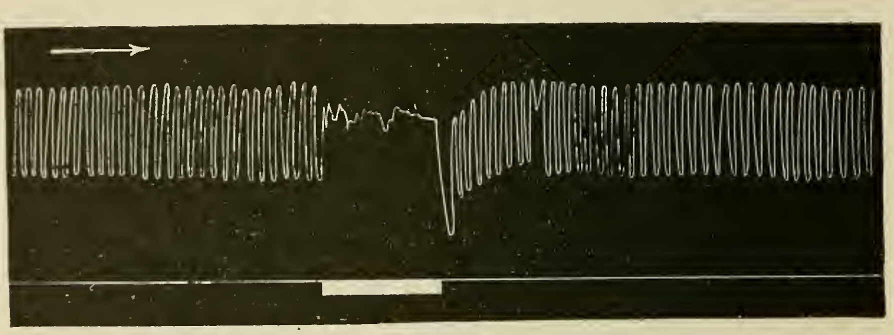

Fig. 22.—Illustrating the arrest of respiration produced by strong stimulation of the central end of the divided pneumogastric. There is a final relaxation of the spasm of inspiration and a relaxation and cessation of respiration in the full expiratory stage. The tracing is made by the method of P. Bert.

fact is made very clear by the slowing of respiration produced by a division of both vagi nerves.

The Natural Stimulus to the Afferent Respiratory Fibers of the Vagus—What, then, furnishes the stimulus producing the normally ascending impulses in the vagus nerve? Of the physical changes associated with respiration in the peripheral distribution of this nerve the changes in the pressure within the alveoli and in their size are the most striking.

That these changes furnish effective stimuli to the vagus nerve is easily demonstrated.

If the trachea is clamped at the end of inspiration when, in other words, the alveoli are full of air, there will result an accentuation of the normal intra-alveolar pressure and the normal collapse of the alveoli will be prevented. A tracing of respiration taken during this time will show an inhibition of all respiration.

In other words the normal stimulation to inspiration with inhibition of expiration is absent. (Fig. 23.)

If the trachea should be clamped at the end of expiration when the alveoli are empty, the influence of the undistended condition of the alveoli will stimulate inspiration, causing a quiet and strong inspiration. The same effect may be produced by positive and negative forced ventilation of the lungs. (Figs. 24 and 25.)

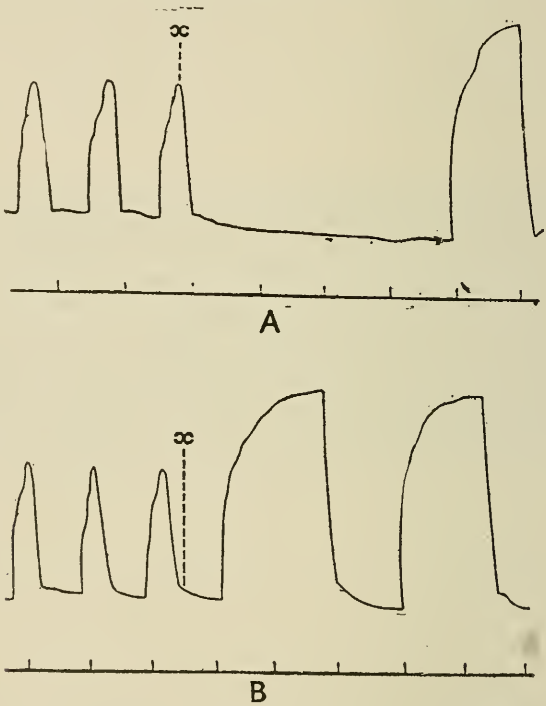

Fig. 23.—Effects of distention-collapse of lung. Both curves are described by a lever attached to a slip of the diaphragm of a rabbit. A contraction of the diaphragm (inspiration) raises the lever; during relaxation of the diaphragm the lever falls. In A, the trachea is closed at *x,* the height of inspiration; a pause follows, during which the lever gradually sinks until an inspiration (a very powerful one) sets in. In B, the trachea is closed at the end of expiration, *x;* then follows powerful inspiration. (Foster.)

It may, therefore, be said that under normal conditions the most important effect produced by the changes in the size of the alveoli is upon inspiration, and that the undistended condition of the alveoli during expiration stimulates inspiration.

The effect is more clearly shown by producing a temporary functional interruption in the conducting power of the vagi nerves, by which means they may be suddenly thrown into activity at the end of inspiration or expiration.

Such a blocking may be produced by cooling them or exposing them to ether narcosis.

If the nerves suddenly become conductive at the end of expiration, impulses will ascend the vagi, stimulating inspiration,

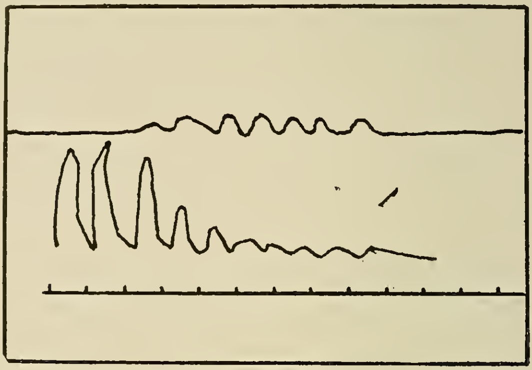

Fig. 24.—Illustrating the effects of positive ventilation. Under positive ventilation the inspiratory contractions of the diaphragm become less and less till they disappear.

but as inspiration proceeds and the alveoli distend, inhibitory impulses ascend the vagi which stop inspiration. Expiration again proceeds, but as the alveoli become contracted, expiration is shortened by a stimulation of inspiration.

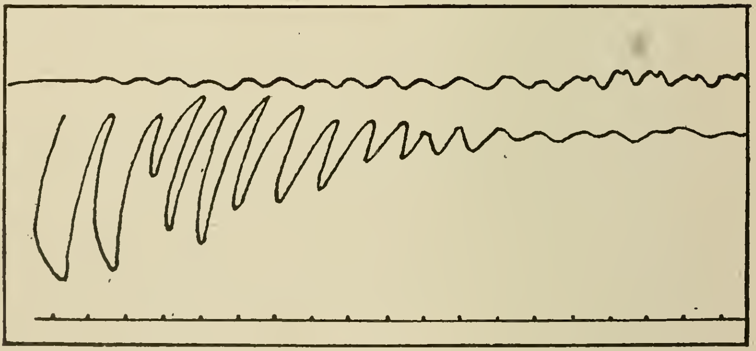

Fig. 25.—Illustrating the effects produced through the vagus by negative ventilation. As negative ventilation was commenced the expiratory relaxation of the diaphragm is seen to become more and more incomplete until it finally enters into continued contraction.

Summary of the Chief Respiratory Functions of the Vagus—Thus the chief function which the vagi nerves perform in connection with respiration is to restrain excessive respiratory movements. The amplitude of expiration is decreased by the excitation of an

impulse in the vagus nerve which leads to inspiration, and the completion of what would otherwise be a deeper inspiration is shortened by the excitation of an inhibitory impulse to inspiration by the distention of the alveoli. After both vagi are cut, respiration becomes slower and deeper, but the degree of aëration of the alveoli remains the same as with the shorter and more frequent respirations present with intact vagi nerves.

During normal quiet respiration the regulating mechanism through the vagus nerve calls into action only the inspiratory inhibitory fibers. Each inspiration is cut short by the mechanical stimulation of these fibers and on collapse of the lung a new inspiration is due to a normal discharge from the center.

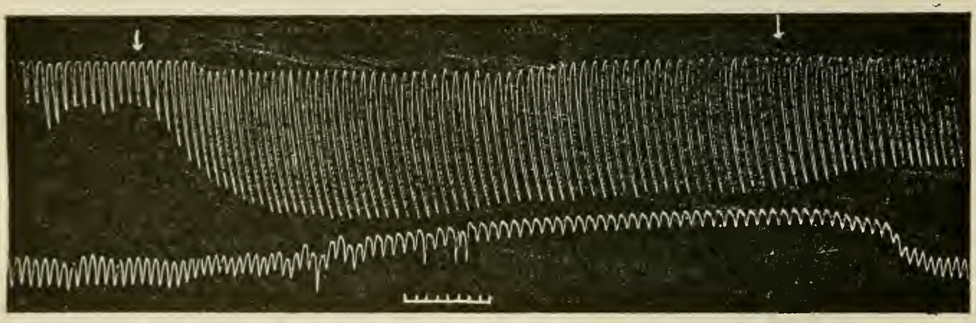

Fig. 26.—Effect of 10.6% CO_2 and 23.3% O_2 on rabbit with vagi divided. The gas was given between the arrows. Zero line of pressure 32 mm. below bottom of tracing. Time two seconds. (Scott.)

The normally ascending impulses in the vagi hold in check the full expenditure of the respiratory efforts. Such impulses must, therefore, be regarded as conservative.

The Importance to the Body of the Afferent Vagal Control over Respiration—While their absence as the result of a simple section of the vagus nerve does not indicate that they are of much importance, yet they are of considerable importance; how much is more accurately indicated when a little greater amount of work is required of the respiratory center. If the percentage of carbon dioxide is increased in the air breathed, an animal possessing both vagi intact will keep the percentage of carbon dioxide constant in its alveolar air by both an increased depth and frequency of respiration; on the other hand, in an animal with divided vagi, respiration is deepened but not quickened. Respiration before the administration of the carbon dioxide was already of considerable

depth as a result of the division of the vagi alone, hence such an animal possesses a greatly diminished power of responding to an increased burden. Such an increased burden may be thrown on

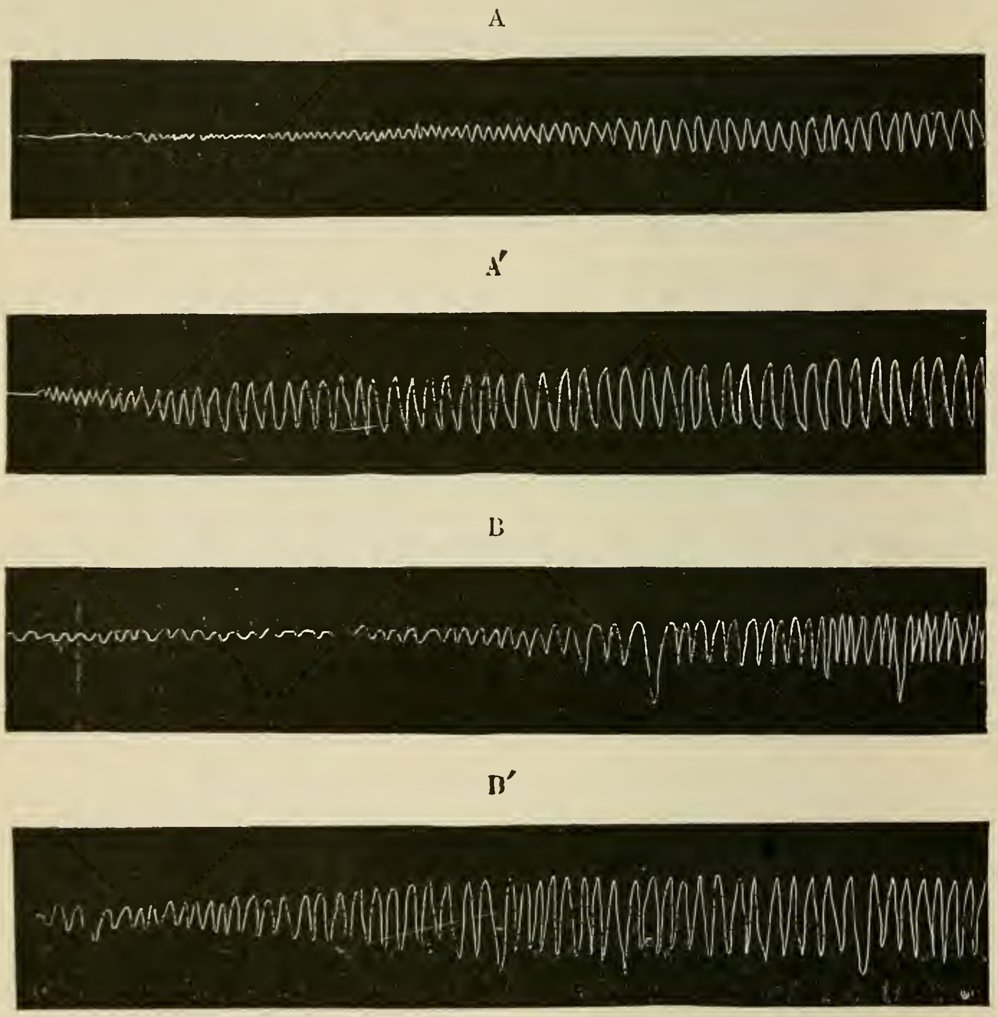

Fig. 27.—Illustrating the inhibitory effects upon the respiratory center of the different vagal impulses which are excited by the distended condition of the alveoli. The curves A, A′, B, B′, represent the onset of respiration after the passing off of apnea induced by forced artificial respiration in the case of the rabbit A, A′ and dog B, B′. The tracings A and B represent the return of respiration in the normal animal. The tracings A′ and B′ represent the return of respiration after the division of both vagi in the case of the rabbit A′ and one vagus nerve in the case of the dog B′.

the respiratory center during muscular exercise. The afferent fibers of the vagi nerves not only conserve the activity of the respiratory center during normal conditions, but also greatly augment its responsiveness, the increased augmentation coming from the

additional afferent stimuli having their origin in the relative size of the alveoli. (Figs. 26 and 27.)

The Effect of Dividing the Vagi after a Division of the Crura Cerebri—The degree with which the vagal fibers are capable of affecting the center is strikingly demonstrated by the division of the crura cerebri which results in a separation of the center from the higher parts of the brain. If before the vagi are divided the medulla is separated from the brain, there will be practically no change in the rhythm of respiration. If, then, the vagi are also divided, respiration becomes replaced by a series of respiratory spasms separated by pauses of a half to one minute and totally inefficient for the needs of the body. Death follows in about half an hour. Its automaticity, if such it may be said to possess, is very limited. The vagus nerve is not the only nerve conveying afferent impulses to the respiratory center. Any sensory impulses upon any nerve whatever may become switched to the respiratory center. Painful impulses and heat and cold impulses frequently are. (Fig. 28.)

ALTERATIONS IN THE EXCITABILITY OF THE RESPIRATORY CENTER AS A RESULT OF CHEMICAL CHANGES IN THE BLOOD.

The afferent nervous connections of the respiratory center are necessary for the control of the activity of the respiratory center. They must be considered as part of the mechanism determining the response of the center in its various phases of excitability. The changes in the excitability of the center are chiefly dependent upon chemical changes in the blood which determine the threshold level of the center, the degree of response, in other words, to the afferent stimuli which reach the center.

The Chemical Changes Transpiring in the Blood which are most closely Related to Respiration—There are two chemical changes constantly occurring in the blood which are directly related to respiration and which are suggested as most probably responsible for variations in the excitability of the respiratory center.

These chemical changes are the variations in the amount of carbon dioxide and oxygen in the blood. It is the sole function of respiration to rid the blood of carbon dioxide and to supply it with fresh oxygen. The mechanism for respiration should, there-

fore, be sensitive to variations from the normal amounts of either both these gases in the blood or to at least one of them, in case the amounts of these gases in the blood always bear a fairly constant ratio to each other, and this condition, depending as it does upon a constant supply of oxygen in the atmosphere, we have seen does obtain under the usual conditions of life.

Asphyxia—It is well understood that the combined effect of an increase of carbon dioxide in the blood and a decrease of oxygen

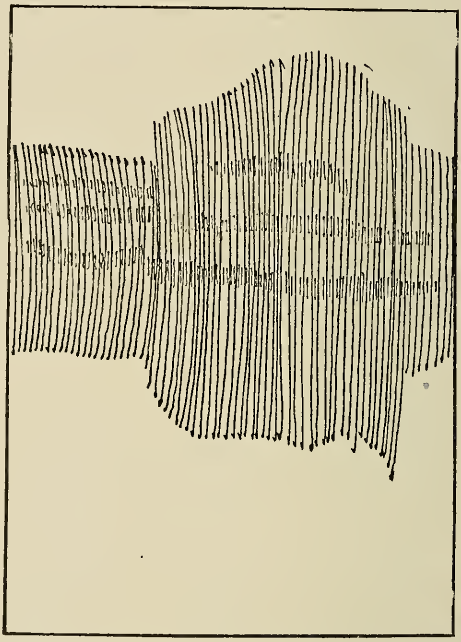

Fig. 28.—To show the augmentation of the respiratory movements caused by stimulation of the sciatic nerve. Experiment upon a rabbit.

is a marked increase in the frequency and depth of respiration. Any interference with proper aëration of the lungs will produce these effects until death will result if the interference is serious enough and long enough continued.

A definite train of symptoms follows such an interference, which are grouped together under the name of asphyxia.

Three Stages are Generally Recognized—1. Stage of hyperpnœa. There is an increase of the frequency and amplitude of respiration.

At first both the inspiratory and expiratory muscles are equally affected. Gradually the expiratory movements become more exaggerated in comparison to the inspiratory movement.

2. Stage of expiratory spasm.

Panting

As this stage is introduced consciousness is lost. The expiratory muscles contract convulsively and there is a spread of the state of excitation from the respiratory center to other centers. The vasomotor center is stimulated with the production of universal vascular constriction. There is an increased secretion of saliva, inhibition or increase of peristalsis and contraction of the pupil.

3. Final stage of inspiratory gasp.

Gradually the convulsive expiratory contractions cease and are replaced by slow deep inspirations. The animal stretches, finally gives long deep gasps, which become ineffectual as exhaustion sets in. The pupils become dilated and all the reflexes become

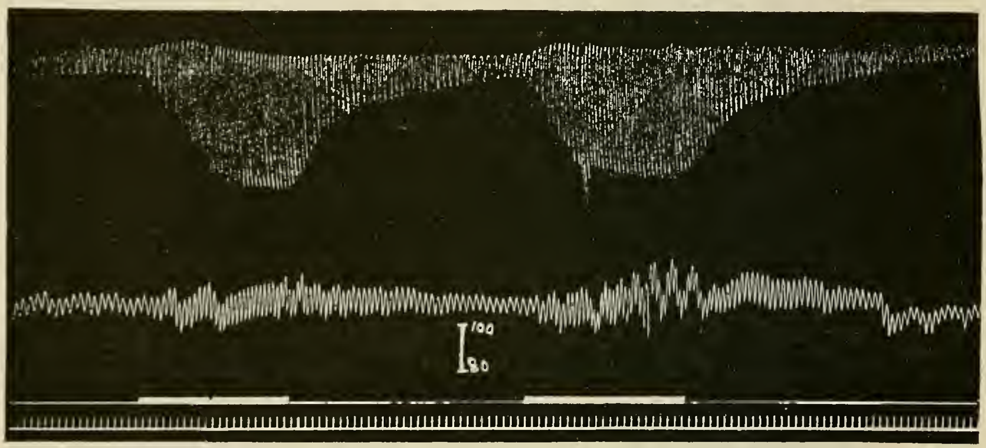

Fig. 29.—Illustrating the effect of an increase of CO_2 without an oxygen lack. Upper line tracing of diaphragm slip. Lower tracing carotid blood pressure. During the first period indicated on signal line the animal breathed 9.6% CO_2, but with 33% O_2. Time tracing, two seconds. Scale, millimeters of blood pressure.

abolished. After four or five minutes the animal takes its last breath and dies.

The Effect of Warming or Cooling the Blood to the Fourth Ventricle—By warming the blood in the carotid the rapidity of the gaseous interchanges may be increased. The effect of this upon the respiratory center is to increase the frequency of respiration without increasing its amplitude, a phenomenon to which the name tachypnœa has been applied. In a similar manner cooling the floor of the fourth ventricle, as by ice, will slow respiration.

In the production of asphyxia in the manner described above there is both an increase in the percentage of carbon dioxide and a diminution of oxygen in the blood. To which of these changes can the effect upon respiration be attributed?

It will be convenient first to consider the effect produced by an increase in the amount of carbon dioxide in absence of any diminution in the normal percentage of oxygen in the inspired air.

The Effect on Respiration of Increasing the Quantity of Carbon Dioxide in the Blood without Altering the Percentage of Oxygen therein—The quantity of carbon dioxide in the blood may be increased without diminishing the amount of oxygen by causing an animal or man to breathe an atmosphere rich in carbon dioxide and at the same time containing a large amount of oxygen. Such experiments always result in a marked increase in the amplitude and frequency of respiration, even a very slight increase in the percentage of carbon dioxide in the air breathed causes an increase in the depth and later in the rate of respiration. (Fig. 29.)

The increased frequency and amplitude of respiration, however, prevent the percentage amount of carbon dioxide within the alveoli from increasing until the amount of carbon dioxide in the air breathed is too great for the compensatory mechanism.

The following table illustrates these facts forcibly:

Percentage of CO_2 in inspired air.	Average depth of respiration.	Average frequency of respiration.	Ventilation of alveoli with inspired air normal = 100.	CO_2 percentage in alveolar air.
0.04	673	14	100	5.6
0.79	739	14	116	5.5
2.02	864	15	153	5.6
3.07	1216	15	226	5.5
5.14	1771	19	498	6.2
6.02	2104	27	857	6.6

It is at least certain, therefore, that CO_2 is a very efficient stimulant to the respiratory center.

The Crucial Factor Determining the Influence of Varying Percentages of Carbon Dioxide in the Alveolar Air is always its Diffusion Tension—While differences in the percentages of carbon dioxide or any other gas in a mixture of gases such as air will always mean a difference in the osmotic tension of such a gas provided the barometric pressure is constant, yet the sole factor influencing the diffusion of gases, as for instance through the walls

of the alveoli of the lungs, is the tension of the gases and not the percentage of the gas present.

At uniform pressures the tension will vary with the percentage, but widely different percentages, in the presence of compensating barometric pressures, may be present without alterations in the osmotic tension.

Thus it was found that when the subject from whom the above table was made at normal barometric pressures was placed in a chamber in which the pressure was raised to 1261, the percentage of carbon dioxide in the alveolar air dropped to 3.42. Carbon dioxide present in a percentage of 3.42 at a pressure of 1261 possesses a diffusion tension equaling that of the carbon dioxide present in the alveolar air at atmospheric pressure. In other words, carbon dioxide present in a percentage of 3.42 at a pressure of 1261 m.m. has the same diffusion tension that a percentage of 5.6 of carbon dioxide has at the normal atmospheric pressure of 760 m.m. As is shown by the following equation, $3.42 \times \frac{1261}{760} = 5.6$, that is $5.6 \times \frac{760}{760}$. The percentage amount of carbon dioxide in the alveolar air in rarefied atmosphere possessing a pressure of 646 m.m. is 6.6. Again, such a percentage of carbon dioxide possesses approximately the same diffusion tension as the percentage of carbon dioxide present in alveolar air at normal barometric pressures. (Fig. 30.)

The following equation demonstrates this fact: $6.6 \times \frac{646}{760} = 5.2$. It may be concluded, therefore, that the diffusion tension of carbon dioxide in the alveolar air is the only important factor controlling the percentage in the blood and that in the presence of widely different barometric pressures the percentage amounts of carbon dioxide in the alveolar air are made to vary in a manner which keeps the diffusion tension approximately constant. These facts indicate that the diffusion tension of carbon dioxide in the blood and, therefore, bathing the centers is most carefully preserved, and because it may be varied by variations in the activity of the respiratory center, that this activity in turn is dependent upon the tension of carbon dioxide in the blood.

The Failure of Any Great Change in the Rate and Depth of Respiration as a Consequence of the Wide Variations in the Diffusion Tension of Oxygen which may accompany Variations in the Diffusion Tension of Carbon Dioxide within the Alveoli—In

the artificial pressures of the two experiments above quoted, 1261 m.m. and 646 m.m., widely different diffusion tensions of oxygen will be present. Thus at the pressure of 646 m.m. of Hg. the percentage of oxygen in the alveolar air was 13.19. It corresponds to a tension of $13.19 \times \frac{646}{760}$ represented by a percentage amount of 10.4 at normal pressures.

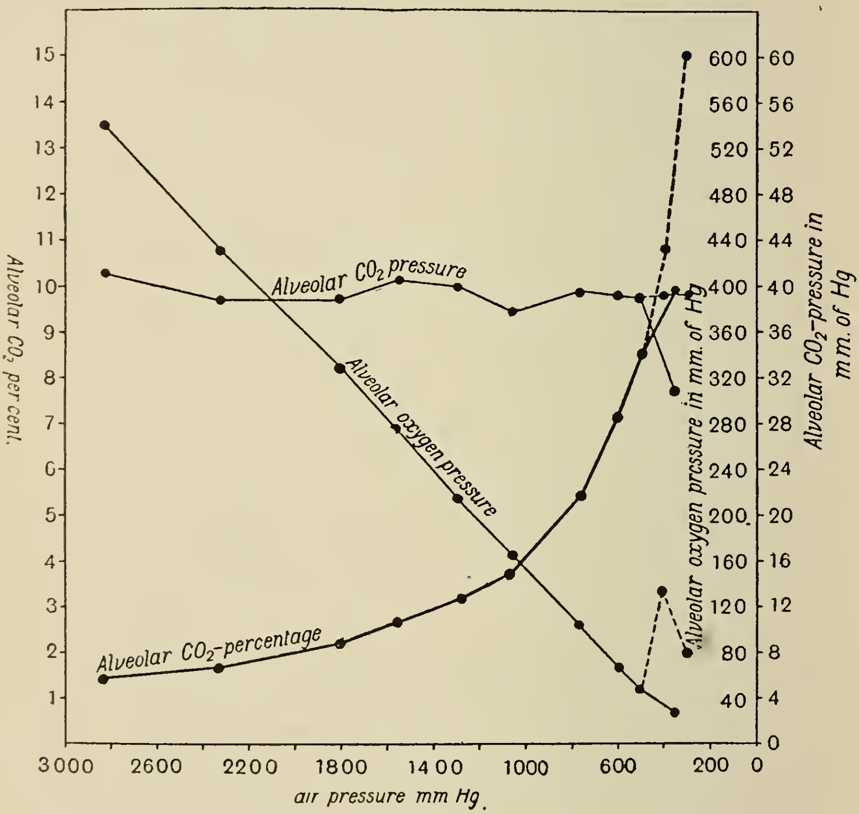

Fig. 30.—Effect of variation in barometric pressure on alveolar gas-pressures and percentage of CO_2. The dotted lines show results when oxygen was added to the air. (Haldane.) As the atmospheric pressure diminishes the percentage of CO_2 increases sufficiently to keep the pressure of CO_2 constant irrespective of a continuous and rapid fall of oxygen pressure.

At the barometric pressure of 1261 m.m. of Hg. the percentage amount of oxygen in the alveolar air was 16.79, which would produce a diffusion tension equaling that of a percentage amount of oxygen in the alveolar air of $16.79 \times \frac{1261}{760}$ or 26.8. These figures demonstrate that wide differences in the diffusion tension of the oxygen in the alveolar air are permitted and, therefore, that no necessity exists for keeping the diffusion tension of oxygen

in the alveolar air constant under the usual conditions of life on this earth.

The Influence of Diminishing the Pressure Tension of the Oxygen without Changing the Normal Alveolar Tension of Carbon Dioxide—The percentage of oxygen in the inspired air can be lowered from its normal of 20.93 per cent. to 12 or 13 per cent. without

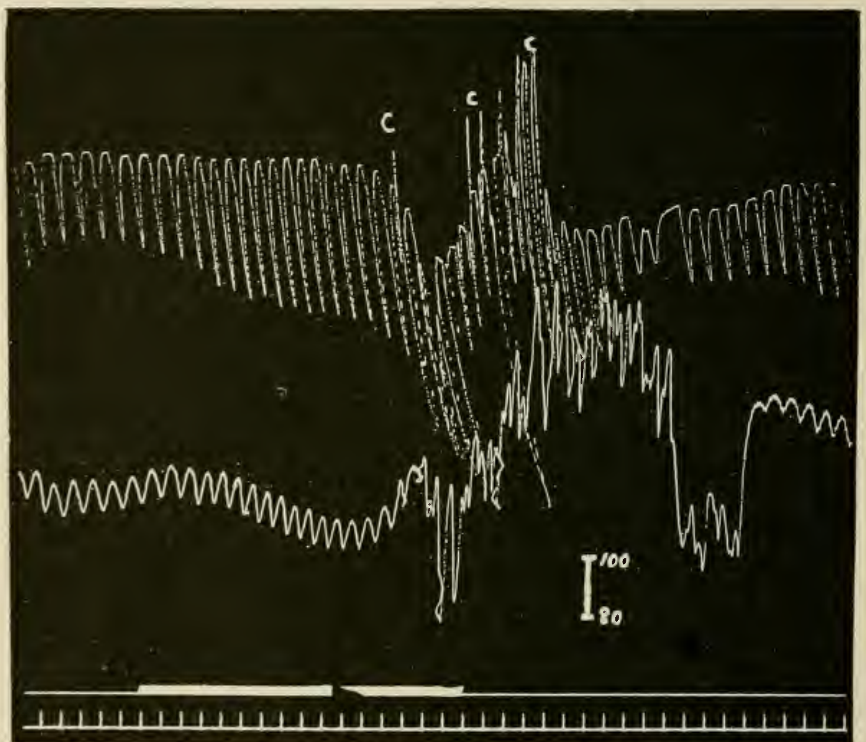

Fig. 31.—Illustrating oxygen lack without excess of CO_2. Upper tracing contractions of the diaphragm slip: lower tracing carotid blood pressure. During the indicated period 5% of oxygen in nitrogen was inhaled. At *C* convulsions occurred. Time tracing, two seconds. (Scott.)

producing any change in the respiration of the subject of the experiment. When the inhaled air contains 13 per cent. of oxygen the alveolar air contains 8 per cent. If the oxygen is still further reduced, there may be increased respiration, but no considerable distress is felt and a subject may actually lose consciousness from deficient oxygenation of the blood before he perceives any deficiency of oxygen in the atmosphere around him. (Fig. 31.)

It is possible to breathe in and out of a bag tightly fitted to the face without the production of hyperpnœa if some means be

taken to provide for the absorption of the collecting carbon dioxide, but not so if this gas is allowed to collect in the bag from the exhaled breath.

The Constancy of the Respiratory Quotient in the Usual Conditions of Life—All conditions of the body calling for an increased elimination of carbon dioxide, as, for instance, during muscular exercise, demand also an increased supply of oxygen. This increased supply of oxygen is accomplished by the very mechanism, namely—respiration—which the body makes use of in order to eliminate the carbon dioxide.

The Second Means of Defense Possessed by the Body against a Deficient Ozygenization by Means of Lactic Acid—It must be remembered that during violent muscular exercise there may be an insufficient supply of oxygen. In such a case lactic acid may be produced in the blood instead of carbon dioxide. If this is the case, the alkalinity of the blood may be somewhat reduced and, therefore, its power to carry carbon dioxide. An increase of acid substances in the blood is also capable of producing dyspnœa.

During violent exercise lactic acid is increased in the blood and urine; and its presence under such circumstances is associated with dyspnœa. Its production may be regarded as a second line of defense of the organism against a deficient supply of oxygen to the alveoli.

The Essential Factor in the Action of Carbon Dioxide and Lactic Acid upon the Respiratory Center—It remains finally to consider whether carbon dioxide should be considered a specific respiratory stimulant or a stimulant only because it is an acid substance, and thus acts like any substance which reduces the concentration of the OH ions or increases the H ions in the blood. The latter view is doubtless the correct one.

All nervous tissue is extremely sensitive to changes in the relative number of OH and H ions surrounding them. The electrical excitation of nerves is probably due to a similar alteration of the relative number of OH and H ions, a change which may be propagated along the different units composing the nerve fibers. The medullary centers appear to be five times as sensitive to changes in this ionic concentration of the fluids bathing them as the spinal centers.

By virtue of these facts, the conclusions seem to be justified

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first, that carbon dioxide stimulates the respiratory center because it alters the relative proportion of OH and H ions in the blood in favor of the H ions.

Secondly, on account of the ease of its production, that it is to be regarded as a most convenient and readily accessible substance for quickly bringing about this change in ionic concentration.

The action of carbon dioxide is, however, much the same as lactic acid, which forms a second substance upon which the body may fall back in case of greater oxygen need.

THE TRANSPORTATION OF THE RESPIRATORY GASES BY THE BLOOD.

Thus far, under the subject of respiration, the mechanism by which the exchange of gases between the external atmosphere and the pulmonary alveoli is accomplished has been considered. It remains to consider the explanation of how the exchanges between the alveoli and the tissues are accomplished.

The Gases Present in the Blood and the Volumes per cent. Present in the Arterial and Venous Blood—If blood is placed in a Torricellian vacuum at the ordinary temperatures, the whole of its contained gases are given off. In this manner from 100 c.c. of blood about 60 c.c. of mixed gases are obtained.

In this mixture only insignificant amounts—.04 vol. per cent. —of argon are present.

Nitrogen is present in amounts varying between 1 and 2 volumes per cent. in both arterial and venous blood. The amounts of oxygen and carbon dioxide differ considerably in the venous and arterial blood. There may be obtained from 100 volumes of arterial blood 20 vols. of oxygen, 40 vols. of carbon dioxide and 1-2 vols. of nitrogen. From 100 vols. of venous blood 8-12 vols. of oxygen, 46 vols. of carbon dioxide and 1-2 vols. of nitrogen.

The Factors Controlling the Diffusion of Gases into Fluid—In order to understand how these gases are taken up and held by the blood it is necessary to be familiar with the physical facts which concern the diffusion of gases into fluids.

If water is exposed to a definite volume of a gas, the gas will be absorbed until the amount passing into the fluid equals the number of molecules passing out of it.

The following factors will determine when this state of equilibrium is reached.

(1) *The absorption coefficient of the gas in question:* All other factors being the same, different quantities of different gases are absorbed by any liquid to which the gases may be exposed. For the same gas the quantity absorbed is always the same when other conditions are unchanged. The number of c.c. of any gas absorbed by 1 c.c. of water at 0° C. temperature is the coefficient of absorption of the gas in question.

(2) *The pressure of the gas:* If a certain bulk of gas is taken up by a liquid at a certain pressure and temperature, double this bulk will be absorbed if the pressure is doubled, the volume remaining unchanged.

Inasmuch as increasing the pressure of a gas diminishes its volume, the same amount of a gas is absorbed when a constant quantity of a gas is exposed to a solution at varying pressures.

(3) *Temperature:* The higher the temperature the less the gas is which will be absorbed, provided the pressure remains unchanged. If the temperature is increased without altering the volume, the pressure will also be increased, and under these conditions the amount absorbed will be proportional to the temperature. We may say, therefore, that the amount of any gas which is absorbed by a liquid with which it is in contact is inversely proportional to the temperature and directly proportional to the pressure.

(4) *Partial pressure:* The amount of any gas absorbed by a liquid with which it is in contact is not altered by the presence of any other gas.

Thus the air is composed of one-fifth oxygen and four-fifths nitrogen; the absorption coefficient of oxygen is 4.89, and of nitrogen is 2.39. If, therefore, air is shaken up with 100 c.c. of water at 0° C. temperature and the normal atmospheric pressure of 760 m.m., 4.89 c.c. $\times \frac{1}{5}$ will equal the number of c.c. of oxygen which will be absorbed, and 2.39 c.c. $\times \frac{4}{5}$ the number of c.c. of nitrogen which will be absorbed.

Therefore the amount of gas dissolved in any fluid is proportional to the partial pressure of the gas.

Estimation of the Tension of a Gas Dissolved in Fluid—If a fluid which is saturated with a gas at a definite pressure is exposed to a pressure of one-half this pressure, it will begin to give off

gas until only one-half the amount of gas is dissolved in the fluid.

It is only by testing solutions against a series of gaseous mixtures containing known proportions of the gas dissolved in the liquid that the tension of any gas dissolved in the liquid can be ascertained. The tension in the liquid will correspond to that one of the series of the gaseous mixtures of known strength in which the partial pressure of the liquid remains unchanged.

Instruments for testing solutions on this principle are called aërotonometers.

The Influence of other Solid Substances in the Solution—The absorption coefficient of water for gases is reduced by the presence of dissolved substances, as proteins or salts. It is also reduced by the presence of solid substances in suspension.

The absorption coefficient of blood plasma for gases is reduced to 97.5 per çent. of that of pure water and of blood containing the corpuscles to 92 per cent. of that of water. The absorption coefficient of blood corpuscles is as low as 81 per cent. of that of water.

The Absorption Coefficient of Water for Carbon Dioxide and Oxygen—The following table gives the absorption coefficient of water for oxygen, carbon dioxide, and nitrogen:

TEMPERATURE	OXYGEN	CARBON DIOXIDE	NITROGEN
0	0.0489	1.713	0.0239
10	0.0380	1.194	0.0196
20	0.0310	0.878	0.0164
30	0.0262	0.665	0.0138
40	0.0231	0.530	0.0118

The Absorption Coefficient of Blood Plasma for Carbon Dioxide and Oxygen—The following table gives the absorption coefficient of blood plasma, blood, and blood corpuscles—for oxygen, carbon dioxide and nitrogen at the temperature stated, *i.e.,* the quantity absorbed by 1 c.c. at atmospheric pressure:

	OXYGEN		CARBON DIOXIDE		NITROGEN	
	15°	38°	15°	38°	15°	38°
Blood plasma	0.033	0.023	0.994	0.541	0.017	0.011
Blood	0.031	0.022	0.937	0.511	0.016	0.011
Blood corpuscles . . .	0.025	0.019	0.825	0.450	0.014	0.010

The Possibilities of the Absorption of Oxygen by a Process of Osmotic Pressure alone—The blood in the lungs is exposed to air (within the alveoli) containing only one-sixth of its volume of oxy-

gen. By this table, therefore, 100 c.c. of blood could not pick up more than 0.36 c.c. of oxygen.

Arterial blood, on the other hand, will yield to the Torricellian vacuum 20 volumes per cent. of oxygen. The oxygen in the blood cannot, therefore, be in simple solution. It must be in chemical combination.

If hæmoglobin is exposed to oxygen it will absorb large quantities—1 gram of crystallized hæmoglobin will absorb 1.4 c.c. of oxygen. The manner in which solutions of oxyhæmoglobin give up their oxygen demonstrates that the oxygen is in chemical combination.

If, for instance, a solution of oxyhæmoglobin is exposed in an air pump to gradually diminishing pressures, very little oxygen will be given off until the partial pressure of the oxygen reaches 30 m.m. At this point a large evolution of oxygen begins, and as the pressure continues to fall to 0 m.m. all the oxygen is given up and the oxyhæmoglobin is reduced to reduced hæmoglobin.

By gradually increasing the partial pressure of the oxygen from 0 m.m., a solution of hæmoglobin will be converted into oxyhæmoglobin, and it will be found that the greatest amount of gas—practically all of that absorbed—is absorbed between 0 and 30 m.m. pressure of Hg.

It must be concluded, therefore, that the oxygen of the blood is not carried in simple solution, but in chemical combination with the hæmoglobin. The possibility of displacing the oxygen from the oxyhæmoglobin by equivalent amounts of either carbon monoxide or nitrogen monoxide still further proves that the oxygen is in chemical combination and not in mere solution.

The Chemical Union of Carbon Dioxide with Hæmoglobin, and the Effect of this Combination on the Dissociation of Hæmoglobin and Oxygen—Hæmoglobin also takes up more carbon dioxide than the equivalent amount of water or salt solution. It must therefore form an unstable chemical combination with hæmoglobin, but in so doing it does not displace the oxygen. Hæmoglobin may be saturated at the same time with both oxygen and carbon dioxide. This double combination of oxygen and carbon dioxide with hæmoglobin increases the ease with which the hæmoglobin parts with its oxygen.

The Influence of the Saline Content of the Blood on the Disso-

ciation of Oxyhæmoglobin—Two other factors alter the ease with which oxyhæmoglobin parts with its oxygen.

The first of these is the saline content of the fluid in which the hæmoglobin is dissolved. If human hæmoglobin is dissolved in

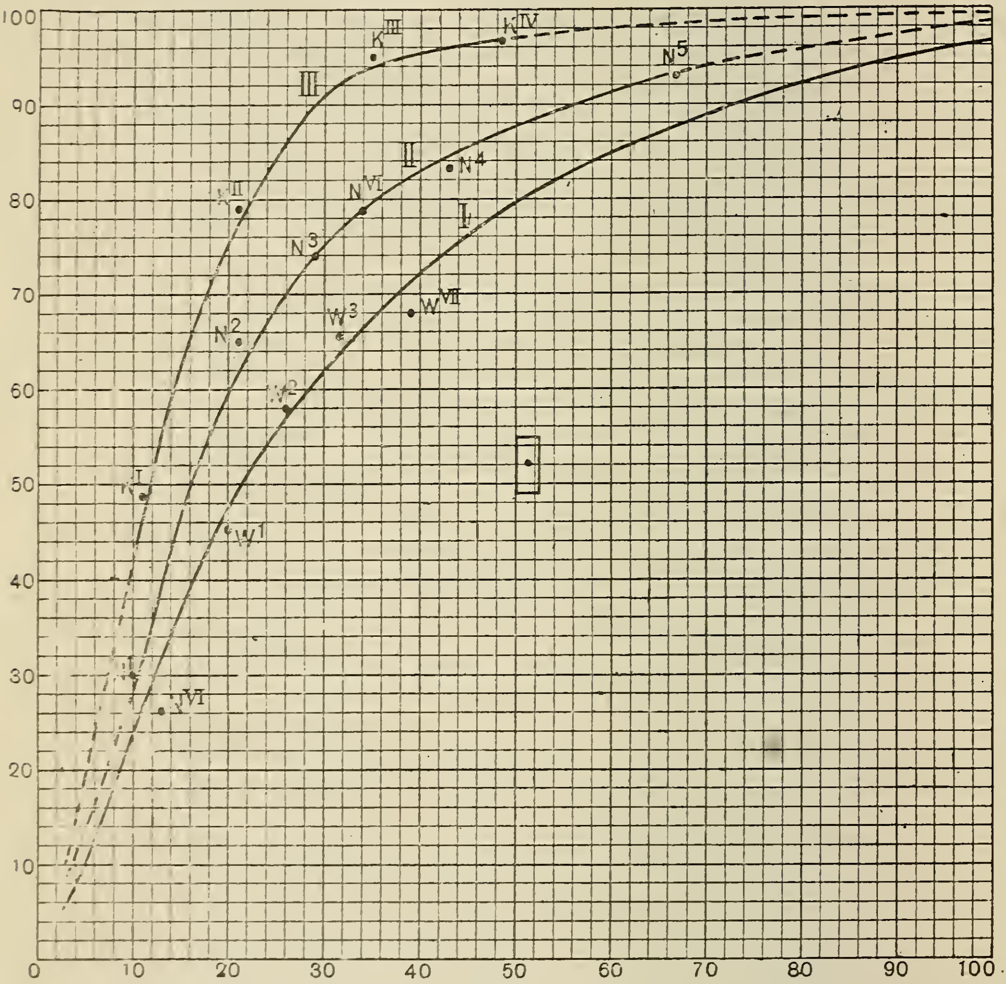

Fig. 32.—Dissociation curve of hæmoglobin in various solvents. I, in 0.9 per cent. KCl; II, in 0.7 per cent. NaCl; III, in water. (Barcroft.)

a saline solution, having the same concentration as dog's blood, its dissociation curve is altered to correspond to that of the dog's blood, provided all other factors are equal. Varying percentages of salts in the solutions of hæmoglobin alter, therefore, the ease of the dissociation of the hæmoglobin with its oxygen. (Fig. 32.)

The Influence of the Reaction of the Blood on the Dissociation of Oxyhæmoglobin—Of far greater influence upon the disso-

is a dilatation of the upper portion of the cervix. It becomes drawn up upon the fetus. Not only does the musculature of the uterus undergo this great hypertrophy, but the vaginal walls become thickened and the round and broad ligaments of the uterus thicker and stronger.

Parturition—Finally when the dilatation of the os has reached a certain point, labor becomes precipitated, and the uterine contractions become strong and frequent enough to expel the fetus. The exact cause of the onset of labor is not thoroughly understood. It has been suggested that it depends upon the collection in the maternal blood of some substance which, during the previous days of its development, is consumed by the fetus. However this may be, labor can always be induced by a dilatation of the os.

In any case it must not be forgotten that the process of parturition involves a number of true reflexes acting through definite centers in the lumbo-sacral region. These centers send impulses not only to the uterus, but also to the diaphragm and abdominal muscles. A destruction of the lumbo-sacral region abolishes the power of parturition, whereas section of the spinal cord in the dorsal region does not do so.

Lactation—The maternal organism not only produces the embryo and provides for its housing and nourishment, and finally when it is able to live a separate existence expels it into the world, but it also provides for its nourishment for the first year of life, during a period when its digestive apparatus is unable to cope with any indifferent food which might be available.

During pregnancy there occurs a remarkable hypertrophy of the breasts of the mother. Actual secretion does not begin, as a rule, until the second or third day after birth. Secretion begins even if the child is born dead, but for the maintenance of secretion suckling is absolutely necessary.

The first secretion of the mammary gland is called colostrum. The colostrum differs from milk in containing little or no caseinogen. It contains in total 3% of proteins. These are lactalbumin and lactoglobulin. Colostrum is also rich in multinucleated cells containing fat globlets. There are probably in part leucocytes which have wandered into the acini, and in part the desquamated epithelium lining of the gland. The colostrum possesses a laxa-

globin. Whatever the carbon dioxide tension in the blood, the hæmoglobin is saturated with oxygen when the tension of this gas in the pulmonary alveoli is 150 m.m., but at lower tensions of oxygen, as for instance in the tissues of the body, the amount of tension of carbon dioxide makes considerable difference. Thus, at an oxygen pressure of 20 m.m. of Hg, the amount of oxyhæmoglobin formed is 67.5 per cent. when the carbon dioxide tension

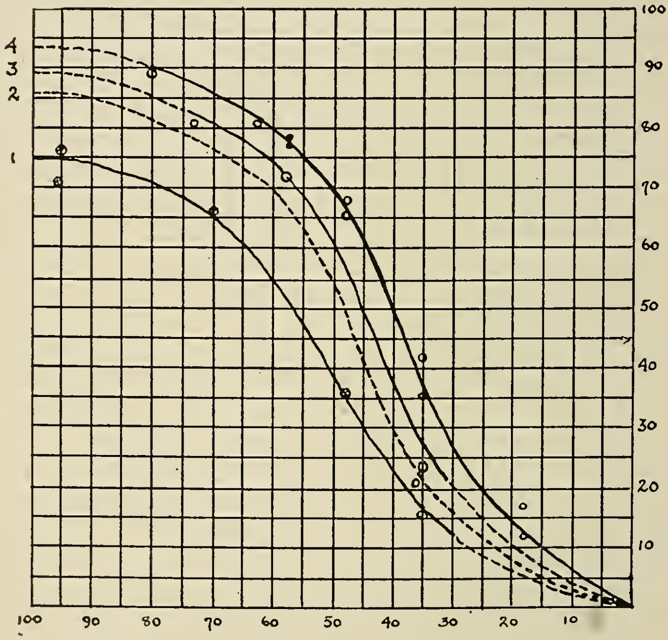

Fig. 34.—Dissociation curve of oxyhæmoglobin in defibrinated cat's blood. 4, cat II at the beginning of the experiment, a normal dissociation curve; 3, cat II after fifteen minutes' rebreathing of a gas in which the oxygen steadily decreases during the experiment; 2, cat II after 21 minutes' rebreathing under the same condition; 1, Cat I after fifteen minutes' rebreathing under the same conditions, but with partial occlusion of the trachea in addition.

in the blood is 5 m.m., whereas the amount of oxyhæmoglobin is only 29.5 per cent. when the tension of the carbon dioxide in the blood is 40 m.m. (Fig. 35.)

These facts have an important bearing upon the processes by which the oxygen is taken up in the lungs and given off in turn to the tissues. In the pulmonary alveoli, the tension of the carbon dioxide in the blood makes little difference in the combining power of the hæmoglobin with the oxygen because of the excess of oxygen in the alveolar air. On the other hand, when this same blood reaches the tissues where there is an increased

production of carbon dioxide and, in consequence, an increase in the tension of this gas in the blood, there is also a diminution of the strength with which the hæmoglobin holds the oxygen.

A knowledge of the actual tensions of the oxygen and carbon dioxide within the circulation through the lungs and tissues makes evident the reality of the influence of amount of carbon dioxide in the blood upon the combining or dissociation power of the hæmoglobin with oxygen.

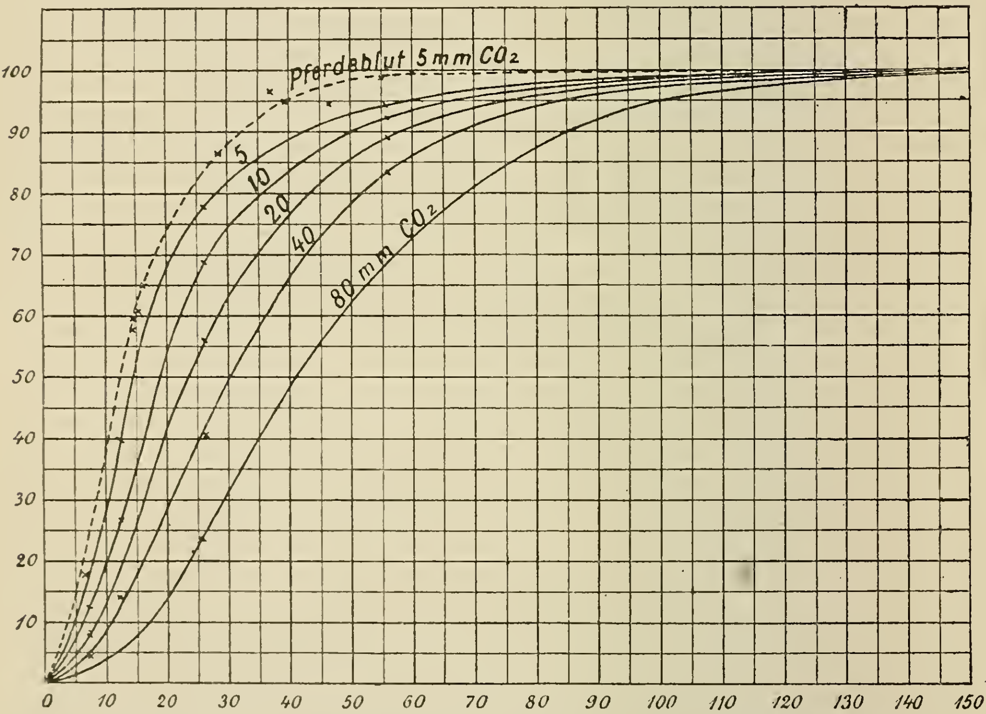

Fig. 35.—The effect of varying tensions of CO_2 on the dissociation curve of oxyhæmoglobin. The ordinates represent percentages of oxyhæmoglobin. The abscissæ represent the tension of the mixed gases to which the solution of hæmoglobin is exposed.

The arterial blood within the pulmonary veins is nearly completely saturated with oxygen. It can take up only two volumes per cent. more oxygen. The venous blood coming from the tissues would require 8 to 10 volumes per cent. more of oxygen to saturate it.

The almost complete degree of saturation (90 per cent.) of the arterial blood is easily and quickly attained by a tension of 30 m.m. of oxygen. One-seventh of the volume of the air within the pulmonary alveoli consists of oxygen, and if the normal atmos-

pheric pressure or tension is 760 m.m. of mercury, there would be at least something over 100 m.m. pressure of oxygen in the pulmonary alveoli. In other words, more than enough pressure or tension to nearly saturate the hæmoglobin in the blood. The excess of oxygen pressure with the alveoli causes the tension of the oxygen in the alveolar air to run in general parallel with the oxygen tension in the arterial blood, but to be always just a little higher—as much as 1 or 2 or even 3 or 4 volumes per cent.

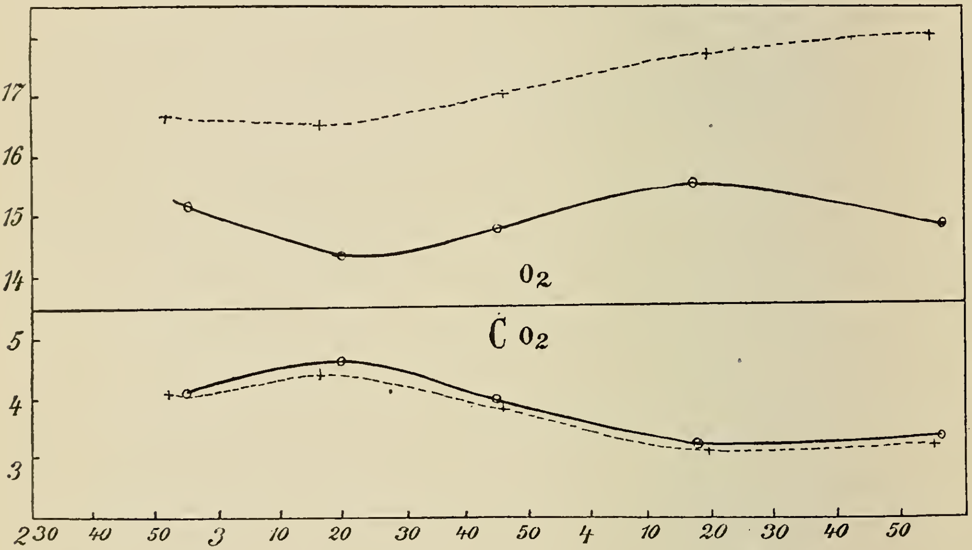

Fig. 36.—The dotted lines represent the tensions in the alveolar air; the interrupted lines the tensions of the gases in the arterial blood.

higher. (Fig. 36.) The blood, thus laden with oxygen, travels to the tissue cells, which are separated from it by the lymph within the lymph spaces. The extraordinary avidity of the tissues for oxygen causes them to consume all the oxygen within this lymph, consequently the blood in its passage through the capillaries gives up its supply of oxygen, the increased tension of carbon dioxide in the lymph facilitating the process.

The capillaries are so short, however, that the blood never remains long enough in contiguity to the lymph to make it possible to part with all of its oxygen. It is thus returned to the lungs only partially reduced. Indeed, the rapidity of the passage of the blood through the capillaries is so great, 0.5 of a second, that it is remarkable that it should part with sufficient oxygen to supply the needs of the tissues. Two factors, however, make this possible:

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one is the great avidity of the tissues for the oxygen, which reduces the oxygen tension in the lymph outside the capillaries to practically 0, and the other the influence of an increased carbon dioxide tension present in the lymph on the dissociation of hæmoglobin.

The Great Avidity of the Tissues for Oxygen—The avidity of the tissues for oxygen is illustrated by Ehrlich's methylene blue experiment. A strong reducing agent will deprive methylene blue of its color. A saturated solution of methylene blue injected into the circulation will permeate both the tissues as well as diffuse evenly through the blood. The organs of an animal filled ten minutes after such an injection are colorless, although the blood is a deep blue color. On exposure of these organs to the atmosphere they become blue, showing that their colorless condition at first was due to rapid consumption of all oxygen and reduction of the methylene blue. The oxidation within the tissues—and it is impossible to conceive of oxidation occurring elsewhere—creates the low oxygen tension in the lymph immediately outside the capillaries.

The separation of sufficient oxygen for the needs of the tissues from the hæmoglobin during the brief transit of the red blood cells through the capillaries is materially assisted by the increased carbon dioxide tension in the lymph intervening between the capillaries and the tissue cells.

It is found that the actual tension of the carbon dioxide in such excretions as bile and urine is 8 or 10 per cent. (60.8 to 76 m.m.) of an atmosphere. The tension in these excretions is approximately the same as it is in the tissues. In venous blood it is rarely over 6 per cent. (46 m.m.) of an atmosphere, or 46 m.m. of Hg. There is therefore the same descending scale of carbon dioxide tension between the tissues, the lymph, and the blood as there is of oxygen between the blood, lymph and tissues. It has been shown that a tension of 46 m.m. of carbon dioxide is quite sufficient to materially hasten the dissociation of oxyhæmoglobin.

It is true that the normal tension of carbon dioxide in the alveoli is about 40 m.m. of Hg, and that the tension in the blood coming from the lungs is only slightly higher than this, so that it may be considered to be also 40 m.m. This tension also diminishes the combining power of hæmoglobin and the strength of the chemical union with oxygen, though of course not so much so as the 46 m.m.

tension of carbon dioxide in venous blood; but in the presence of the high oxygen tension (107 m.m. of Hg) in the alveoli, it in no way prevents the almost complete saturation of the blood with oxygen, whereas the increase in the tension of the carbon dioxide to 46 m.m. in the capillaries has a very definite effect in augmenting the delivery of the oxygen from the hæmoglobin to a lymph in the presence of an oxygen tension of practically 0 within the lymph around the capillaries.

The following table gives the progressive changes in the respiratory gases between the atmospheric air and the tissues:

	Inspired Air		Alveolar Air		Arterial Blood		Venous Blood	
	Percentage	Osmotic Tension	Percentage	Tension	Percentage	Tension	Percentage	Tension
O_2..	20.96%	132 m.m.	13.5%	107 m.m.	20 Vol. %	10 m.m.	8-12 Vol. %	37 m.m.
CO_2.	.04%	.3040 m.m.	6%	40 m.m.	40 Vol. %	40 m.m.	46 Vol. %	46 m.m.

The Condition in which the Carbon Dioxide is carried by the Blood—From 100 c.c. of dog's venous blood about 50 c.c. of carbon dioxide may be obtained by means of the pump. The tension of the carbon dioxide in the blood, however, is about 40 m.m. of Hg, or a little more than one-twentieth of an atmosphere. Inasmuch as water shaken up with one atmosphere of carbon dioxide at the temperature of the body will dissolve 50 volumes per cent. and blood slightly less, on the basis of mere solubility, 110 blood shaken up with carbon dioxide at a pressure of only one-twentieth of an atmosphere would only pick up less than $\frac{50}{20}$ or 2½ volumes per cent. We have seen, however, that 50 c.c. of carbon dioxide may be extracted from 100 c.c. of blood; therefore, far more carbon dioxide exists in the blood than can be accounted for on the basis of solubility. The carbon dioxide must consequently exist in the blood chiefly in the condition of chemical combination. We have seen that part of the carbon dioxide, but only a small portion, is chemically combined with the hæmoglobin. Most of the carbon dioxide must exist in chemical combination in the plasma.

When blood is reduced to ash by heat more sodium is found in the ash than is enough to satisfy the acid radicals, chlorine, sulphates, and phosphates which are present in the ash, particularly as some of the phosphates and sulphates in the ash have been derived from the proteins of the blood. This sodium existed,

therefore, in the blood as sodium carbonate or bicarbonate. The carbonates and bicarbonates may also represent a part of the carbon dioxide of the corpuscles.

In addition to combining in this manner to form inorganic salts, carbon dioxide may also combine with the proteins of the plasma.

The following table has been given as representing the various ways in which the 40 c.c. of carbon dioxide, obtainable from 100 c.c. of dog's arterial blood, may be distributed:

In simple solution in plasma and corpuscles			1.9 c.c.
As sodium bicarbonate	in corpuscles	6.8	
	in plasma	12.0	—18.8 c.c.
In organic combination with hæmoglobin		7.5	
In organic combination with proteins of plasma		11.8	—19.3 c.c.

The Influence of Disodium Phosphate on the Liberation of Carbon Dioxide from its Solutions—If so much carbon dioxide is present in blood as sodium bicarbonate, it should be possible to dissociate a simple aqueous solution of sodium bicarbonate in the same manner that the sodium bicarbonate can be dissociated in the blood. From an aqueous solution of sodium bicarbonate only 50 per cent. of the carbon dioxide may be obtained, and none at all from an aqueous solution of sodium carbonate.

If, however, there is added to a solution of sodium bicarbonate, sodium hydrogen phosphate, it will be possible to extract all of the carbon dioxide from the mixture; moreover, such a mixture will take up large quantities of carbon dioxide from gaseous mixtures in which the pressure of the carbon dioxide is only slightly above the pressure of the gas in the fluid. When such a mixture is exposed in a vacuum the sodium bicarbonate—at least a portion of it—undergoes dissociation with the formation of sodium carbonate. The latter reacts with the acid sodium phosphate with the formation of disodium phosphate, carbon dioxide and water according to the following reaction: $2NaH_2PO_4 + Na_2CO_3 = 2Na_2HPO_4 + CO_2 + H_2O$. Furthermore, the reverse of this change takes place when the mixture containing Na_2HPO_4 is exposed to carbon dioxide. At once NaH_2PO_4 and Na_2CO_3 is formed, and finally $NaHCO_3$. These reactions do not actually take place

in the blood to any large degree, because the blood contains only the merest traces of phosphates. The reactions nevertheless demonstrate the probable mechanism. Little doubt exists that as the phosphates in a solution in the presence of CO_2 may give up a part of their sodium for hydrogen the proteins in the blood by a similar mechanism may perform the same function. The addition of proteins to a solution of sodium carbonate will make it possible to obtain all the carbon dioxide from the solution by exposing the same to a vacuum.

The Quantitative Exchange of Gases in the Blood, and the Provision for Excessive Demands—In the above discussion regarding the physical conditions controlling the interchange of gases during respiration, no reference has been made to the total amounts of the gases diffusing through the alveolar wall. It is true that during rest sufficient differences exist in the alveolar tensions of the gases to permit of saturation of the blood with oxygen and a maintenance of a carbon dioxide tension of between 40 and 46 m.m. of Hg, but these facts tell us nothing about the possible rates of diffusion and the provisions for excess during strain.

It has been estimated that the lungs contain 3000 c.c. of air during a state of medium distention and that there are about 700,000,000 alveoli, each of which possesses a diameter of 0.2 m.m. On the basis of these figures the blood is exposed to the alveolar air over a surface amounting to 90 square meters or a surface 50 ft. $\times$ 20 ft.

This is a minimal surface, as no account is taken of the increase of this surface by the projections of capillary loop into the alveoli.

Probably 140 square meters would be a more correct figure. In its exposure over this surface the blood is spread out in a layer not thicker than the diameter of a blood corpuscle.

The thickness of the lining tissue separating it from the cavity of an alveolus is not more than .004 m.m. Through such a thin layer of tissue a difference in oxygen tension of 35 m.m. would cause 6.7 c.c. of oxygen to pass per minute for each square centimeter of alveolar wall. Through the whole surface, therefore, 6083 c.c. of oxygen could diffuse each minute. As the amount of oxygen needed by man during rest is only 300 c.c. per minute there is ample provision for a greater supply during times of

greater oxygen consumption by the tissues. Moreover, it must be remembered that the tension of the oxygen in venous blood is 37 m.m. of Hg, or 5.3 per cent., while the oxygen tension in the alveolar air is 107 m.m. Hg; a difference, therefore, of 70 m.m. of Hg exists.

The rate of diffusion of carbon dioxide is much more rapid (twenty-five times) than that of oxygen.

The normal amount of this gas expired is 250 c.c., and a difference of pressure of only .03 m.m. of Hg would be sufficient to permit of the loss of this much carbon dioxide per minute through the total alveolar surface.

Inasmuch as the carbon dioxide tension in the alveolar air is 40 m.m. of Hg, and in the venous blood of 46 m.m., there exists a difference of pressure between the two of 6 m.m. of Hg—more than 180 times enough to account for the normal loss during rest.

The organism may be subjected to strain in two ways—either the consumption of oxygen may be extreme, as during muscular exertion, or the body may be required to breathe a rarefied atmosphere. The dissociation power of hæmoglobin in the presence of a normal tension of carbon dioxide of 40 m.m. Hg is greatly influenced when the tension of the oxygen in the alveoli falls below 50 m.m. Hg. At 40 m.m. oxygen tension hæmoglobin may be only 65 per cent. saturated. If a human being is absolutely at rest, the oxygen tension in the alveoli may fall to between 30 and 35 m.m. of Hg without the individual experiencing distress.

In order to test the effect of low percentages of oxygen in the blood, a man may be allowed to breathe a mixture of pure nitrogen and oxygen, that is, air freed from carbon dioxide. The experiment must be so arranged that the quantity of oxygen may gradually be diminished. When the oxygen is diminished to as low as 12 per cent., no change whatever will be noticed in the respiration, even though the lips and face may appear slightly blue from deficient oxygenation. If the oxygen percentage is lowered still further, a certain amount of hyperpnœa may occur, but in the case of many individuals actually a state of unconsciousness may be induced before any ill effects are noticed by the subject of the experiment. If the percentage of oxygen in the inspired air is slowly reduced to 10-12 per cent. and allowed to remain there, symptoms of discomfort will be experienced. These symptoms are

usually headache, nausea or vomiting, and precordial distress. The limit to which the oxygen may be reduced varies in different individuals. Life cannot be sustained at a lower alveolar pressure than 27 to 30 m.m. of Hg.

On and near the top of high mountains the percentages of oxygen in the air become so reduced on account of the low atmospheric pressure, that extremely low alveolar pressures are present in individuals living in such atmospheres. At a height of 5000 meters the total atmospheric pressure is reduced to one-half, and the oxygen pressure to only 11 per cent. of an atmosphere. Individuals ascending to these heights are also consuming more oxygen owing to the exertion of climbing. They are, therefore, very susceptible to mountain symptoms, which are precisely similar to those just described as present in an atmosphere of 10-12 per cent. of oxygen. All the members of a party ascending Monte Rosa, 4560 meters high, where the oxygen tension in the air was 89 m.m. and in the alveoli 37 to 57, suffered from mountain sickness.

Due to oxygen starvation at these high levels there is a lack of supply of this gas to the heart and in consequence the circulation begins to fail. There is a failure of judgment and inability to perform coördinated movements, with Cheyne-Stokes breathing. The symptoms do not as a rule increase until death takes place. There is, therefore, a compensation and the compensation which takes place is due to the production of acid substances—the lactic acid which has been previously mentioned.

By prolonged stay at high altitudes the body may become so far accustomed to the changed conditions that life is more easily sustained.

Among the factors responsible for the compensation are:

1. The increase in the Hydrogen ionic concentration of the blood.

2. The quickening of the pulse.

3. Relative increase in the number of red blood cells and total amount of hæmoglobin. The average number of red blood cells in a cubic millimeter of blood of the inhabitants of the Cordilleras, 4392 meters high, is 8,000,000.

Probably no man could live permanently at a height of 5000 meters. The highest altitudes ever ascended by man was in the famous balloon ascension of Tissander, who reached a height of

8600 meters, a height equal to the Himalayas. Although oxygen inhalation was used, two of this party succumbed.

4. The stimulation of the blood-forming organs extends to the muscular tissue. There is actually an increase in weight. The individual becomes again a growing animal, and nitrogen is retained.

Effects of Overventilation—The opposite condition to strain may be produced by overventilating the alveoli. If, for instance, a resting human being breathes forcibly, or the lungs of an animal are rapidly inflated and deflated, the tension of the carbon dioxide will fall much below 40 m.m. of Hg within the alveoli. Inasmuch as carbon dioxide diffuses so rapidly, the tension in the blood will fall to a corresponding amount. One result of this fall of carbon dioxide tension within the blood will be a failure of the respiratory center to receive the normal stimulation from the carbon dioxide in the fluids bathing it and to which it is accustomed. In consequence, respiration will cease until carbon dioxide again collects in the blood. Such a failure of respiration is called apnœa. It is in no way related to the increased quantity of oxygen usually present in the apnœic condition, nor to afferent stimulation of the vagus nerve due to increased distention of the alveoli, inasmuch as it will not occur under the same condition of forced artificial respiration if the carbon dioxide content of the inspired air is increased to 4.5 per cent.; on the other hand, it will occur as rapidly if the lungs are forcibly ventilated with some inert gas like nitrogen, whether an abundant supply of oxygen is present or not, because under such condition the tension of the carbon dioxide pressure within the pulmonary alveoli is reduced as effectively as if the lungs are artificially ventilated with air.

The term acapnia is applied to that condition producing apnœa, in which there is a diminution of carbon dioxide in the blood. The opposite condition in which there is an excess of carbon dioxide in the blood is called capnia.

It has been demonstrated that, while the respiratory center is sensitive first to changes in the carbon dioxide tension in the blood, it is to some degree sensitive to a lack of oxygen, so that in extreme degrees of oxygen lack the respiratory center is stimulated by this factor also. Accompanying the condition of lack of oxygen there

is an increase of lactic acid in the blood, and this substance, as we have seen, is an efficient stimulant of the respiratory center.

Cheyne-Stokes Respiration—Under certain pathological conditions there may exist an interference with the supply of oxygen to the blood, an interference which may not equally affect the more diffusible carbon dioxide. Under such conditions there is at one time a stimulation of respiration due to the lack of oxygen and formation of lactic acid in the blood. This period of forced respiration results in the diffusion of the carbon dioxide out of the blood.

The oxygen lack in the meantime has been made good. As soon as the carbon dioxide tension is lowered the respiratory center ceases to act and the respirations become shallow and less frequent. During this period carbon dioxide again collects in the blood and again an oxygen lack with increase of lactic acid sets in. When such a condition exists, respiration is alternately deep and frequent and shallow and infrequent.

The name "Cheyne-Stokes" respiration is applied to the condition.

Conditions under which the Nitrogen in the Blood may become a source of danger to the Individual—The nitrogen of the atmosphere must be considered entirely as an inert gas. During the transition from a high to a low pressure it may, however, become the cause of serious injury to the body. In these instances, due to the sudden relief of the pressure, the nitrogen may bubble from the blood and cause embolism of the minute vessels, particularly of the nervous system.

Divers suffer from these accidents, and in order to prevent these symptoms and even death itself, it is necessary that the transition from the high to the low pressure should be made gradually.

Methane and hydrogen are absolutely inert gases when occurring in the atmosphere. Not so carbon monoxide, the action of which has been explained in the section on blood.

Ammonia, chlorine, sulphur dioxide, nitric oxide, are harmful solely from their irritating effects.

Conditions under which the Rebreathed Air becomes Dangerous, and the Measure of the Contamination of a Confined Atmosphere—Carbon dioxide does not become a menace to health

unless it is increased to a point much greater than that to which it is increased in a room which is disagreeable to the senses. The atmosphere of such a room is said to be stuffy, and many unpleasant symptoms are attributed to its closeness. The unpleasant symptoms are probably due to other factors, the most important of which is heat. The unpleasantness of the air under such conditions is largely due to volatile, unpleasant emanations from the mouths, skin, and breath of the persons who have contributed to the unpleasantness of the confined air. It is extremely doubtful whether such volatile substances are really harmful. Probably they are not.

It is usually conceded that the air of a confined space does not become unpleasant until the carbon dioxide in it increases to 0.1 per cent. Every individual should be supplied with sufficient air to permit of the carbon dioxide being kept below 0.1 per cent. In this manner carbon dioxide may be used as a guide to the degree of impurity of air and the amount of ventilation needed.

An adult man gives off 0.6 cu. ft. of carbon dioxide every hour. Therefore in one hour's time he would raise the carbon dioxide in 1000 cu. ft. of air from 0.04 to 0.1 per cent.

Each individual should therefore be supplied with 2000 cu. ft. of fresh air every hour, in order to keep the carbon dioxide percentage down to 0.07 per cent.

INTRACELLULAR OXIDATIVE PROCESSES.

The mechanism by which oxidation takes place in the cell is bound up with the question of the mechanism of the essential nature of the activities of cell life. Although most of these, certainly as regards anything more than the grossest outlines, are beyond our power to unravel, yet certain processes occur in the organic world which serve as hints of the general nature of oxidation in the cell.

In the first place intracellular oxidation cannot be a simple absorption of oxygen by the oxidizable substance; for the class of foodstuffs which yield energy to the body by oxidation are dysoxidizable, that is, they show no tendency to combine with the oxygen of the air at normal temperatures.

Second, oxidation within the tissues is a specific process. Even auto-oxidizable substances, as phosphorus or carbon monoxide, after entering the body, are excreted unchanged. Then again, of the sixteen hexoses, only four are serviceable to the body as a source of energy. Of the leucines *l*-leucine can alone be oxidized, its isomer *d*-leucine is not.

Third. Oxidation in the body proceeds at temperatures varying between 5°-40° C., and is not dependent on the high temperatures necessary to oxidize the foodstuffs apart from the activities of the body.

Fourth. When certain defects in metabolism are present, notably in diabetes, oxidative processes, otherwise normally conducted, cannot be carried out.

The various conditions of oxidation within the body may be satisfied by two means, by which oxidation is accomplished in the inorganic world.

Any reducing substance acts as such because it possesses such an affinity for the oxygen molecule that it tears apart. Now if it unites with only one of the two resulting atoms, the other atom is left free to act as an oxidizing agent. It is quite certain that reducing substances are formed in the tissues in association with the oxidative processes also going on there. Such a process cannot, however, be the whole of the explanation of intracellular oxidation, as it would not explain the specific element in the process. Other processes also occurring in the inorganic world furnish, however, further hints.

When glucose is boiled with an ammoniacal solution of cupric hydrate, it is oxidized with the formation of cuprous hydrate, which last in turn takes up oxygen from the air and becomes again cupric hydrate. In other words, the cupric hydrate acts as an oxygen carrier from the atmosphere to the dysoxidizable substance glucose.

This mode of action is precisely similar to that by which ferments or hydrolytic agents act. It seems permissible, therefore, to explain the specific character of intracellular oxidation by assuming the presence of oxidizing ferments. Such ferments are called oxidases. Such ferments are widely distributed in nature.

The browning of a freshly cut surface of an apple or potato is due to the action of an oxidase on a chromogen in the apple.

In many cases a single ferment is not involved alone but a mixture of an organic peroxide and a ferment named a peroxidase, because it has the power of splitting off active atomic oxygen from the organic peroxides.

These peroxidases will act in the same manner on hydrogen peroxide and are not the same as the ferments called catalases, which also rapidly decompose hydrogen peroxide. A catalase acts according to the following equation: $2H_2O_2 = 2H_2O + O_2$, while a peroxidase produces the following change: $H_2O_2 = H_2O + O'$.

It may be assumed that the peroxide radicals in the cells exist as side chains, and when fully satisfied act as organic peroxides, and when incompletely satisfied as reducing agents. The setting free of peroxidases from a condition in which they exist as zymogens is also a factor the reality of which must be assumed in order to account for the fact that oxidation does not occur within a cell, as a result merely of the presence of oxygen, but rather in response alone to the specific need that the process of oxidation should occur.

QUESTIONS AND ANSWERS

Page 4

Q. Define internal and external respiration.

A. External respiration is the assimilation of oxygen by the blood in the lungs.

Internal respiration is the assimilation of oxygen by the body cells.

Q. Describe the anatomical structure of the lungs and their adaptation to external respiration.

A. See text.

Page 14

Q. Describe the pleural cavity and how is it formed in the growing embryo?

A. The pleural cavity is a completely closed sac intervening between the lungs and the walls of the thorax. It consists, therefore, of a costal pleura and a visceral pleura, and the two are contiguous to each other. The pleural cavity is formed by a reduplication of the primitive visceral pleura into the thoracic cavity.

Page 16

Q. Explain the mechanism of external respiration.

A. By the enlargement of the chest cavity in a downward and outward and upward direction there is created a negative pressure within the pleural cavity, which overcomes the natural elasticity of the lung fibers and causes them to enlarge in a manner to still fill the thoracic cavity. The air within the alveoli thus becomes rarefied, and the external atmospheric air rushes in and restores the normal alveolar pressure. During expiration the muscles which have produced during inspiration the enlargement of the thoracic cavity relax and permit the weight of the chest walls to fall upon the lungs. This weight, assisted by the retraction of the elastic fibers within the lung tissue, expels the inspired air from the alveoli.

Page 18

Q. What are the muscles of inspiration and expiration?

A. Inspiration: diaphragm, external intercostals, quadratus lumborum. Expiration: internal intercostal, the costal portion of the external intercostals, the abdominal muscles.

Page 32

Q. What are the variations in intrapleural pressures during inspiration and expiration?

A. —4 mm. during expiration to —9 mm. during inspiration.

Rate of Respiration

Normal adult 10 - 18 per min.

Newborn child 44 - per min

Child of 4 yrs - 26 per min

RESPIRATION

Page 36

Q. Into what quantities may the respired air be divided?
A. See text.

Q. What is the quantity of carbon dioxid eliminated in 24 hours and the amount of oxygen assimilated?
A. 250 c. c. of CO_2 per kilo per hour, 300 c. c. of O_2 per kilo per hour.

Page 38

Q. What is the composition of inspired and expired air?
A. See text.

Page 40

Q. What is the tension of the combined gases in the alveoli?
A. 710 mm. when the atmospheric pressure is 760 mm. because there is 50 mm. tension of water vapor in the alveoli.

Q. What proportion of the tidal air reaches the alveoli?
A. 360 c. c., as there is a dead space of 140 c. c. in the trachea and bronchi.

Page 42

Q. Describe the respiratory center and the function which it performs.
A. The respiratory center is a collection of nerve cells situated approximately in the floor of the fourth ventricle, but not limited to a too definitely circumscribed region, which is sensitive to certain changes in the blood and to certain afferent impulses from the lungs and periphery, and whose axons pass either directly or indirectly to the motor cells of the respiratory muscles. In this manner the changes in the blood and afferent impulses from the periphery and from the lungs are able to alter the rate of respiration in a most efficient manner, by affecting many muscles and affecting them variously from a single region.

Page 50

Q. What effect is produced upon the respiratory center through the vagus nerve?
A. A quickening of the rate of respiration and a diminution of its amplitude, due chiefly to a stimulation of inspiration. In the case of strong stimulation an augmentation of the same effect on the center may produce a spasm of respiration in the inspiratory phase.

Q. What is the natural stimulus to the afferent respiratory fibers of the vagus nerve?
A. The degree of distension of the alveoli. An empty condition of the alveoli producing a stimulation of inspiration and inhibition of the expiratory muscles, while a filled condition of the alveoli produces an inhibition of all respiratory effort.

Page 54

Q. What kind of afferent fibers to the respiratory center are contained in the vagus nerve?
A. See text.

— $\frac{CO_2}{O_2}$ R.Q. the avg. value is .82

function – Control the rate + depth of resp.

Resp. C. is sensitive to N. control
chem. control.
N. control thru aff. imp. by Vagus
a. inspirat. on alv. filling + the
stimulus i [illegible] of
Units nerve [illegible]
The chem. control is by a hormone

Page 60

Q. What is the advantage to the body of the vagal control of respiration?

A. It conserves the activity of the respiratory function so that during periods of greater demands upon it there exists a considerable margin of possible increase in activity. It furnishes an additional stimulus to the respiratory center of much importance, and alone makes respiration possible after division of the crura cerebri or, in other words, keeps the alveolar content of carbon dioxid normal in the presence of large increase in the respired air.

Page 64

Q. What are the two conceivable chemical stimulants to the respiratory center?

A. An excess of carbon dioxid in the blood and a deficiency of oxygen.

Page 66

Q. What is asphyxia?

A. A series of symptoms following an interference with respiration.

Page 70

Q. Which of the two respiratory gases is the efficient factor in causing the increased respiration of beginning asphyxia, or, in other words, which of the two gases is the hormone of respiration, and how may the fact be demonstrated?

A. Carbon dioxid, because an animal breathing increased quantities of carbon dioxid and normal or increased amounts of oxygen is stimulated to a more rapid respiration, and within limits to a sufficiently rapid respiration to keep the alveolar content of carbon dioxid constant under similar conditions of atmospheric pressure; whereas oxygen lack, without changes in the amount of carbon dioxid in the respired air, produces no change in respiration.

Page 72

Q. What is the crucial factor in the chemical control of respiration by carbon dioxid?

A. Its diffusion tension within the alveoli. See text for illustration.

Page 78

Q. What other chemical stimulant to respiration is there in addition to carbon dioxid?

A. Increased quantities of lactic acid in the blood.

Q. What is the common factor involved in the influence of carbon dioxid and lactic acid on the respiratory center?

A. The alteration of the relative proportion of the H and OH ions in the blood in favor of a greater H ionic concentration. In other words, an increased acidity of the blood.

CO_2

of CO_2 in Blood + not to Insuff of O —

from tissues — ...

... > CO_2 in ... < opposite ...

of blood to tissues ...

What is responsible for CO_2 in ...

Amt of CO_2 found ... by

... + depends upon amt ...

in ... of tissues. CO_2 ...

... from ... at a certain ...

... in the ... full ...

... of ...

Page 80

Q. What is meant by volumes per cent, and what are the volumes per cent of the carbon dioxid and oxygen in arterial and venous blood?

A. See text.

Page 82

Q. What are the factors controlling the diffusion of gases between the gases and fluids?

A. See text.

Page 86

Q. To what extent do the absorptive possibilities of blood for oxygen explain the capacity of the blood to unite with oxygen, and what does this fact indicate?

A. To only 1/60 of the amount with which blood combines. The fact indicates that the oxygen forms a chemical combination with the blood.

Q. What constituent of the blood forms this chemical combination with oxygen and what are the physical conditions under which the combination is normally formed?

A. The hemoglobin of the red cells. This substance becomes quickly saturated with oxygen as the partial pressure of this gas exceeds 30 mm., or equally quickly gives up its oxygen as the partial pressure falls below 30 mm.

Page 88

Q. What other conditions alter the power of hemoglobin to hold oxygen?

A. The amount of CO_2 present in solution, the quantity of salts and the kind of salts in solution, and the reaction of the solution.

Page 90

Q. What facilitates the dissociation of oxyhemoglobin in the capillaries?

A. The increased quantity of carbon dioxid picked up by the blood in the capillaries, which makes considerable difference in the speed of dissociation because there is also a low tension of oxygen in the tissues.

Page 100

Q. Give the percentages and tensions of the respiratory gases in the different stages of their transfer between the atmospheric air and the tissue cells.

A. See text.

Q. In what form is carbon dioxid transported by the blood?

A. See text.

Page 104

Q. What margin exists for meeting excessive demands of the body for oxygen and for the elimination of carbon dioxid?

A. The body can assimilate 20 times as much oxygen as it needs during rest, and can eliminate 180 times the quantity of carbon dioxid normally eliminated during rest.

to a chain prod. [illegible]

Q, act of [illegible] as has a

Inhibit effect on another act.

In

RESPIRATION

Page 108

Q. What is the influence of high altitudes on respiration?

A. In high altitudes there is a great diminution of the tension of both O_2 and CO_2 in the alveoli. Under these conditions high percentages of CO_2 collect in the alveoli in order to maintain the normal tension in the blood. To permit of the collection of these high percentages the respiration is relatively less frequent, just the action tending to diminish the normal tension of oxygen in the alveoli, which already is much lowered by the high altitude. Those who habitually live in high altitudes compensate to a certain degree by developing a polycythemia.

Page 110

Q. Define apnea, acapnia and capnia.

A. See text.

Page 112

Q. Define Cheyne-Stokes respiration.

A. See text.

Q. What is caisson's disease, and how is it produced?

A. See text.

Page 114

Q. What are the conditions under which rebreathed air becomes dangerous?

A. When the carbon dioxid content increases to .1 per cent, not because this percentage of carbon dioxid is harmful, or because it is a measure of a harmful quantity of any other toxic substance imparted to rebreathed air, but because of the moisture and heat which become oppressive when air has been rebreathed to this extent.

Q. How much fresh air should be supplied to each individual per hour?

A. 2,000 cubic feet.

Page 116

Q. What is the explanation of intracellular oxidative processes?

A. By the ferments, oxidoses and peroxidoses, which, as all ferments, act as true transfer agents of the oxygen from the fluids around the cells to the oxidized substances.

LECTURE NOTES ON PHYSIOLOGY

BY

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HYGIENE

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HYGIENE

The science of hygiene is very closely related to the science of bacteriology.

Subdivisions of Hygiene and Its Definition—The subject of hygiene may be divided into two very unequal and two very distinctly separated portions. First, those hygienic precautions, which the individual should exercise in order to preserve his health quite apart from relations with other individuals. Second, those hygienic precautions, serving to protect the individual from those dangers to his health which depend upon his relations with other individuals.

The first subdivision may be entitled personal hygiene and from it must be excluded all diseases of bacterial or parasitic origin, because all such diseases depend upon some primary source of infection in some other individual. It deals solely with the prevention of ill health, which comes from depression of the general vitality, or from ill health due entirely to metabolic disturbances. Such causes of ill health relate almost entirely to dietary errors, improper protection from injury by trauma, cold, heat, water, or improper relations between work, rest, and recreation. All these matters are, with few exceptions, directly under the control of the individual and are, therefore, purely personal matters. Even some of these matters, however, concern social relations; particularly, when groups of individuals become subjected to improper personal hygienic conditions by other individuals on whom they are dependent for education or employment.

Again many matters, which concern strictly personal hygiene, become of importance chiefly because they make the individual an easier prey to bacterial infections. Comparatively few matters falling under the classification of personal hygiene have no relation to bacterial infection. In fact, those matters of personal hygiene having no relation to bacterial infections occupy a very small space at the present time in discussions on hygiene.

For these reasons, hygiene may be fairly accurately defined

as that science which aims to establish healthful relations for individuals with each other. These relations concern chiefly the mutual relations between individuals or relations which virtually concern, solely, the prevention of the spread of pathogenic bacteria from one individual to another. For this reason General Hygiene is most intimately related to Bacteriology.

General Hygiene concerns the source, the kind, the quality, and the preservation of the food which we eat, the quality of the air which we breathe, and the water which we drink, and the water in which we bathe. By deviations from a standard in any of these particulars not only may the food, air or water become a direct means of transfer of bacteria from one individual to another; but also the individual may become so weakened that he may become an easier prey to accidentally transferred bacteria, which under other conditions of health he would be able to resist.

Under the conditions mentioned, he becomes a source of danger to others. A part of the protection, therefore, which all individuals have the right to expect from the State is the protection from sources of danger arising from the poor state of health in other individuals. The State has the right to step in and alter any condition facilitating the transfer of bacteria from one individual to another, or any condition rendering any individual more liable to receive and, therefore, to spread the pathogenic bacteria.

The science of hygiene investigates all conditions permitting the transfer of pathogenic bacteria with a view of preventing the actual transfer. As a result regulations have been formulated and laws passed which have already led to a greatly decreased death-rate in all the large cities.

FOOD

Divisions of Foodstuffs Which We Eat—Foodstuffs may be divided into proteins, carbohydrates, and fats. For the normal individual that diet which most spares the activities of the various internal organs and still supplies sufficient energy and nutritional units is the most economical.

Amounts of the Three Foodstuffs Constituting an Economical Diet—The body at all times needs a definite proportion of pro-

teins, carbohydrates, and fats. This proportion varies little during periods of extreme exertion and periods of rest. In health, a largely protein or strictly vegetarian diet is not the most economical. In regard to amounts, the average individual should eat food having a caloric value of 3,333 per diem.

For the average working individual this should be divided as follows:

Protein	120 grams to 130 grams
Fats	55 grams to 100 grams
Carbohydrates	500 grams

As the heat value of 1 gram of protein is approximately 4.1 calories,

and of 1 gram of fat 9.3 calories,
and of 1 gram of carbohydrates 4.1 calories,

this diet would furnish the individual with 3,053 to 3,513 calories a day.

For women	Proteins	94 grams
	Fat	45 grams
	Carbohydrates	400 grams are suggested.

These quantities have a caloric value of 2,444.

Relative Proportions of the Three Foodstuffs in the Various Commercial Foods—It is important to know something of the relative proportions of the three foodstuffs in the various foods which we eat and their approximate caloric value. What would otherwise be a laborious calculation has been made very easy by the tables which the United States Department of Agriculture has published.

Proportion of the Foodstuffs and Caloric Value of the Meats—Of the meats including beef, liver, tongue, roast beef, steak, ham, pork, veal, mutton, lamb, and poultry,

The proteins vary from 15.3 to 23.9 per cent,
The fats vary from 2.5 to 30 per cent,

according to the amount of obvious fat present. Lean poultry has the least and fat pork the most. Steak, mutton, and beef have values of 10, 18, and 28 per cent. The caloric value varies chiefly with the quantity of fat present. A high content of fat greatly

runs up the caloric value of the meat. In lean poultry and steak, for instance, in which the fat is small in amount, the caloric value is 505 to 875. In pork and beef it is 1,580 to 1,620 calories. In fish the proteins vary from 14 to 22 per cent. The average is about 18 per cent. The fat in salmon is between 3 and 17.8 per cent. The average is about 5 per cent. The caloric value runs from 335 to 1,080 according to the amount of fat present.

Relative Digestibility and Preparation of the Meats—Beef and the white meat of poultry is probably the most digestible of the meats; mutton is a close second; veal varies greatly with the individual; pork is the hardest to digest. As a rule the digestibility is rendered difficult by a large content of fat.

Raw meat is more easily digested than cooked meat, though cooked meat is more completely digested.

Broths are infusions of meat. They usually consist chiefly of salts in solution but their protein contents may be increased by the addition of lactic acid to the water with which the infusion is made. Boiled meat or stewed meat usually lacks many of the salts which improve the flavor of the meat. It consists of coagulated meat. The coagulation point of the protein of meat is 134° F. If the temperature is raised to 160°, gelatin is formed from the collagen of the connective tissue. Meat becomes far tougher if the stewing is conducted at a higher point than 180°.

Meat may be fried. The fat which is used for frying should be very hot so that the surface of the meat may be quickly coagulated. This permits the retention of all the juices and prevents the fat penetrating very far into the meat.

Characters of Good Meat—Good meat should have a uniform color or should be firm and elastic and give out no objectionable odor.

Digestibility and Preparation of Fish—Fish in general is more indigestible than meat. Fish is very liable to decompose rapidly. The rapidity with which it decomposes is increased by allowing it to die slowly. Fish, therefore, should be quickly killed after catching and eaten when very fresh.

Fish is preserved by smoking and salting. Both of these methods increase its indigestibility and greatly reduce the pleasantness of its flavor. Mollusks, oysters, and clams are the most digestible of fish. Oysters contain 1 to 2 per cent of fat and 6 to 8

per cent of proteins. Lobsters and crabs are the most indigestible forms of fish. The fishes rich in fat, as trout and salmon, are relatively to other fish more indigestible.

The Parasites of Meat and Fish—Meat and fish are a source of danger chiefly from the parasites and bacteria which they contain.

Fig. 1. Cestodes (tapeworms). 1, Taenia saginata. A, Head of taenia saginata. 2, Dorsal view of the head. 3, Apex view of head, showing depression in center. 4, Isolated, elongated segments. 5, Bothriocephalus latus. 6, Ripe segments of taenia saginata. B, showing location of sexual organs. 7, Half-developed segments of taenia saginata. Illustrations drawn from specimens. (Fischer.)

Tapeworms—Two forms of tapeworm commonly infecting man may infect meat and one form may infect fish. Beef may transmit the *Taenia saginata* (Figs. 1 and 2), 15 to 20 ft. long; pork may contain the *Taenia solium* (Fig. 3), 6 to 12 ft. long; and such fish as the sturgeon, pike, perch, and salmon of certain regions may contain the *Bothriocephalus latus*, 25 to 30 ft. long.

All tapeworms consist of a head provided with hooks and suckers by which they obtain a hold within the intestinal mucosa and a long chain of segments united behind the head. Within the segments there develops a uterus containing a large number of eggs.

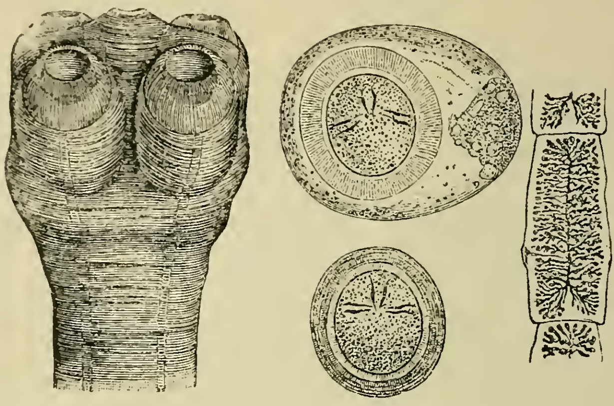


Fig. 2. Head, egg and neck of taenia saginata. (Jaksch.)

These become fully developed in the most posterior segments which break off and are passed out with the feces. The cow, pig, or fish, eating contaminated grass or drinking contaminated water become infected by these eggs. The coating of the egg becomes dissolved in

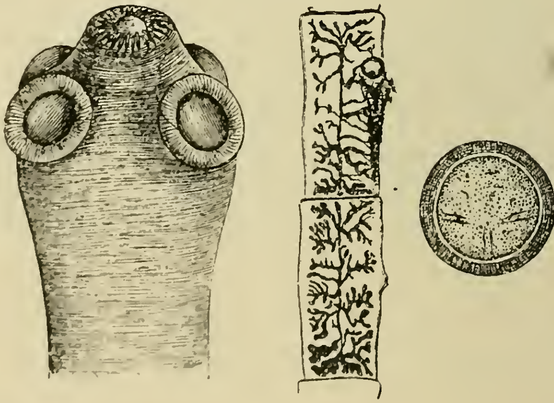


Fig. 3. Head, neck and eggs of taenia solium. (Jaksch.)

the stomach and the minute worm inside begins to bore through the intestinal wall and, reaching the circulation, makes its way to all the muscles of the body. Within the muscles they form little bladders 1-25 to 3-4 of an inch in diameter. These are known as *Cysticerci.*

Trichina Spiralis—Another parasite infecting and obtained from the flesh of pigs is the *Trichina spiralis* (Fig. 4). This worm is far more dangerous than the tapeworm. In the pig the worm is encapsulatedly coiled within the muscles, especially the muscles of the diaphragm, the intercostal muscles, and the jaw muscles (Fig. 5). It appears as a small white speck.

When the flesh is eaten the worm is liberated in the stomach of the human being. Within the intestinal tract, the worm becomes

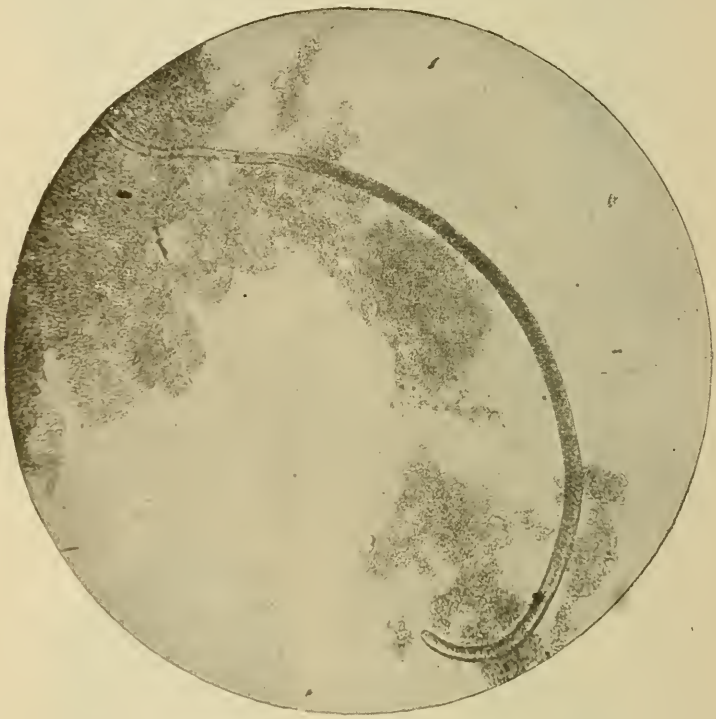


Fig. 4. Free trichina. X 38. (Harrington.)

sexually mature and grows as large as a fine thread just visible to the eye. Here the female produces its young and as many as 500 new larvæ may come from one individual worm. These then begin to bore through the intestinal wall reaching the circulation and finally, carried to the muscles, the embryos become incysted. During the migration of the worm from the gastro-intestinal canal to the muscles, the infected individual suffers serious symptoms, not infrequently resulting in death and protracted at times over a period of 2 to 6 weeks.

Bacterial Contamination of Meat—Meat may be unfit for use

because of the bacteria which it may contain. Some of these bacteria are pathogenic bacteria capable of living within the human body and causing there a specific infection. Other bacteria are harmful not because they produce a specific disease within the human being, but because they produce poisonous substances in the meat itself. These toxic substances are derived from the protein of the meat which becomes split into soluble poisons called ptomaines.

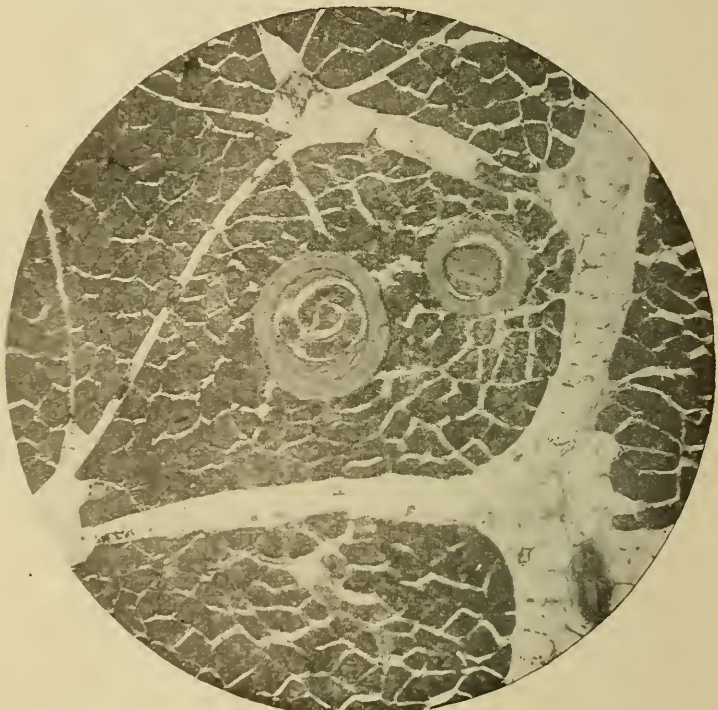


Fig. 5. Trichinae in pig muscle. X 75. (Harrington.)

Tuberculosis—Among the disease-producing organisms transmitted by meat, tuberculosis is doubtless of the greatest importance. The relation of bovine tuberculosis to human tuberculosis has already been discussed in the section on bacteriology. While the *tubercle bacillus* does not infect cattle, the bovine variety of the *tubercle bacillus* constitutes a very real danger to human beings, and especially to children. The abdominal and glandular forms of tuberculosis are frequently of bovine origin.

In Berlin during the year 1892-1893, 15.1 per cent of the cattle, 1.55 per cent of swine, 0.11 per cent of calves, and 0.004 of sheep

had tuberculosis. In Great Britain 30 per cent of the cows are estimated to have had tuberculosis. In Mexico 33 per cent of the cattle slaughtered had tuberculosis. In New York State not more than 1 per cent and 2 to 3 per cent of Jersey or Guernsey cows have the disease. Throughout the United States, on a rough average, about 10 per cent of the cattle respond to the tuberculin test.

Because of the fact that the muscles are rarely affected, the danger of eating tuberculous cattle is not very great. In consequence, various rules have been adopted in various countries. The Royal Commission in England permits the use of tuberculous cattle for food if care has been used in the dressing of it. The French do not permit the use of infected animals if the tuberculosis is generalized. In Prussia the meat of emaciated animals is not allowed to be used for food.

In the United States meat of tuberculous animals is considered unfit for use as food, if, first, it contains *tubercle bacilli* or is impregnated with toxic substances, or if associated septic infections are present in the animal; second, if the animal is emaciated and has generalized tuberculosis. The presence of isolated and few lesions does not render it unfit for use as food. Although the muscles of tuberculous animals do not often contain the tubercular lesions, it has been abundantly proved that other animals may be infected by feeding them upon the meat of tuberculous cattle: and the injection of the expressed juices of the muscles of tuberculous animals into guinea-pigs has caused infection of the guinea-pigs in a fair proportion of instances.

There can be absolutely no question about the very real danger of drinking milk from tuberculous cows and, for this reason alone, rigid examination of all cows used as a supply of milk should be made by the tuberculin test and all animals responding positively should be killed.

Typhoid Fever and Cholera—These diseases are frequently transmitted by oysters and cockles and sometimes by clams. A number of important outbreaks of typhoid fever have been directly traced to the eating of oysters contaminated by allowing sewage to flow over their beds. In an oyster, the typhoid *bacillus* will live for two or three weeks. Oysters may, therefore, be purified by keeping them in pure water two or three weeks after digging.

No oysters are, however, fit to eat which have come from waters

Immunization of infection

a. Prominent ... [illegible] of health

b. Care in dressing

c. [illegible] ... of infection [illegible] they may

be prevented by keeping [illegible] [illegible]

[illegible] c. Prevention, destruction of diseased [illegible]

contaminated by human discharges or the refuse from collecting boats. Moreover, oysters should not be transported in open scows through polluted waters.

Ptomaine Poisoning—Meats may become dangerous because they contain virulent poisons called ptomaines. These are manufactured in them by specific though not pathogenic bacteria which have contaminated the meat during the time of the keeping after killing. The possibility of the meat containing fatal quantities of these poisons depends solely upon the introduction into it of the proper bacteria. It does not necessarily bear a relation to the stage of decomposition in meat though unquestionably spoiled meat is far more dangerous.

A number of these poisons have been isolated. They are neurin, cholin, and one identical in action with muscarin, neuridin, putrescin, cadaverin, and another identical in its action with curare.

Though these poisons are primarily formed in the meat before it is eaten, there is no reason to believe that the bacteria responsible for them cannot continue the production of more poison within the intestinal canal, and it is not known in how far this may be the case.

A certain number of these bacteria closely resemble the paratyphoid *bacillus*. Many are spore forming *anaërobes*. Among others which have been isolated are the *bacillus botulinus*, the *bacillus enteritidis sporogenes coli*, the *bacillus enteritidis*, the *bacillus bovis morbificans*, the *bacillus marsiliensis*, the *bacillus Friedenbergensis mirabilis*, the *staphylococcus pyogenes aureus*. The *bacillus botulinus* produces an exceedingly virulent poison causing symptoms resembling those produced by diphtheria and tetanus toxins. Sausage meat is liable to contain these poisons, if care is not exercised in its manufacture.

The symptoms of ptomaine poisoning come on with great suddenness within 3 to 36 hours, and sometimes not until from 2 to 9 days. In the latter case they are probably due to the multiplication of the bacteria within the intestinal canal. The same cause renders infected individuals liable to relapse. The symptoms are characterized by great abdominal pain, diarrhea, vomiting, extreme prostration, anuria, and even paralysis. The meat of animals dying of pyæmia, pleural pneumonia and puerperal fever is especially dangerous.

Eggs—The whole hen's egg contains:

65.5 per cent water
11.9 per cent protein
9.3 per cent of fat
9 per cent of salts
and per lb. they contain 635 calories.

The white of an egg contains:

	Water	Protein	Fat	Ash		Calories per lb.
	86.2	12.3	.2	.6	per cent	250
The yolk	49.5	15.7	33.2	1.1	" "	1,705

In regard to digestibility the white of the egg is more digestible raw or soft boiled; while the yolk is more digestible when hard boiled; so that there is little difference between soft and hard boiled eggs from the standpoint of digestibility. Eggs are far more appetizing when fresh and probably, therefore, more digestible. Unless, however, spoiled, so that they simply cannot be eaten, stale eggs are not harmful to the health as they are not subject to contamination.

Milk—Milk is usually obtained from cows. It should not be used as food for fifteen days before calving nor until ten days after. It should not contain less than 8.5 per cent of solids and 3.25 per cent of milk fat. Cow's milk contains:

	Water	Protein	Fat	Sugar	Mineral matter	
	87	3.30	4	5	.70	per cent
Human milk contains:	87	2.29	3.78	6.21	.31	" "

Two important proteins occur in milk casein and lactalbumin. The mineral matter consists chiefly of the phosphates and chlorides of potassium, sodium, calcium, magnesium and iron.

The phosphates are in excess of the chlorides and the potassium salts in excess of the sodium salts.

The specific gravity of milk should vary between 1.029 to 1.034.

In the early days of lactation the sugar in milk is dextrose and not lactose.

Milk contains a number of ferments, trypsin, pepsin, amylase (not in cow's milk), lipase, and reductase.

Bacterial Contamination of Milk—Fresh milk is said to inhibit the growth of bacteria, but this property of milk is soon lost, and it is the bacteria, which kept milk may contain, that render it dangerous to health.

When once started, bacteria multiply with great rapidity in milk. It forms a most valuable culture medium for bacteria. The conditions under which milk is obtained preclude prevention of the entrance of bacteria into it.

Microscopical study of thirty-five teats of cows showed that not one was free from bacteria and that these belonged chiefly to the class of pyogenic bacteria. Similar results have been obtained by the examination of cow's udders. Even with every precaution against contamination during milking, precautions which include washing the cow's legs, tail, udders and teats, a thorough washing of the hands of the milking man and a careful straining of the milk through sterile strainers, the freshly drawn milk will contain on the average 242 to 267 bacteria to the cubic centimeter. It is true that one-third of the samples drawn under these conditions showed no bacteria, but one-tenth of the samples contained more than 5,000 to the cubic centimeter.

When freshly drawn milk contains a large number of bacteria, the bacteria are chiefly of intestinal origin and belong to the lactic acid ferment producers. The most important one is the *streptococcus lacticus,* which is probably only a variety of the *streptococcus pyogenes.* Another is the *bacillus acidi lactici,* which is probably identical with the *bacillus lactis aërogenes.*

Other bacteria belong to the *bacillus coli communis* group. Some twelve varieties of peptonizing ferment-producing bacteria have been isolated from milk. Three of these are seriously pathogenic to animals. A butyric acid ferment-producing bacterium has been isolated. They are strictly spore-forming anaërobes and include among them the *bacillus enteritidis sporogenes* or the *bacillus aërogenes capsulatus.*

Provisions for Obtaining Pure Milk—Many milking devices have been made which are designed to draw milk in a manner which will prevent hands coming in contact with the cow and at the same time will exclude all external sources of contamination. None of them, however, have been found successful. For some unknown reason

their use has been accompanied by a reduced production of milk by the cows.

The best that can be done in order to procure uncontaminated milk is to milk into a scrupulously clean pail, completely covered, with the exception of a sieve-covered opening 6 in. in diameter through which to receive the milk; to keep the cows and their stalls clean; to wash their udders and teats before milking and above all to thoroughly cleanse the hands of the milkers before milking and insist upon their wearing clean clothes during milking. After milking, the care with which the milk is bottled and kept will have much to do with its bacterial content. Milk obtained from healthy cows with care and only containing, approximately, 6,000 bacteria to the cubic centimeter, within a short time after milking will contain, even if kept at 45° F., increased numbers—in five hours' time it will contain 1,933 bacteria to the cubic centimeter, and in 48 hours' time it will contain 17,816 to the cubic centimeter.

Milk obtained with only ordinary precautions contains to each cubic centimeter:

	In the winter	In the summer	
Shortly after milking	16,650	30,366	bacteria
After 24 hours	31,000	48,000	"
After 48 hours	210,000	680,000	"

Twenty samples of milk, some of which had come from a distance of two hundred miles, contained, immediately on arrival in the city, 52,000 to 35,200,000 bacteria to the cubic centimeter. The average was 5,669,000. The lactic acid producing bacteria exert an inhibitory effect on the growth of most of the other bacteria in milk and develop better than other varieties at low temperatures, below 40° F., for instance. They entirely inhibit the growth of many other bacteria originally present in milk. On this account while the number of bacteria increase in milk with time, the number of varieties decrease. The question of sterilization and Pasteurization of milk has already been discussed in the section on bacteriology. Neither process is desirable when they can be dispensed with. Neither is the use of such preservatives as formaldehyde or salicylic acid desirable. The least objectionable preservative is, perhaps, hydrogen peroxid though this is only temporary in its effect. A 0.2 per cent of a 3 per cent solution of hydrogen peroxid

will sterilize milk and a 1 per cent will keep it fresh for one week. The stinging taste, however, is perceptible in .01 per cent of hydrogen peroxid. The only unobjectionable and reliable way of keeping milk pure is to obtain it under conditions which are scrupulously cleanly and to keep it at temperatures which are at least only a few degrees above the freezing point.

An important source of adulteration of milk is water, which is sometimes used for dilution purposes. The farmer's pump has been responsible on more than one occasion for typhoid fever.

Condensed Milk—Condensed milk is milk evaporated to 1-3 of its volume and sweetened with cane sugar. If sufficient fat should be added to bring its content of fat up to the fat standard for milk. it would raise the cost of condensed milk to 9 to 12 cents a quart. Inasmuch as condensed milk cannot be heated during its preparation to a sufficiently high temperature to kill the bacteria which it contains, without caramelizing the sugar, it usually contains a large number of bacteria. The number of bacteria present has been 900 to 10,000,000 to the cubic centimeter.

Butter—Butter is the separated fat of milk. Good butter should contain as follows:

84 per cent of fat
12 " " of water
1 " " of cocein lactose
.5 to 2.5 per cent of salts.

The fats are chiefly trioleates, palmitates, and stearates, which together compose 92.25 per cent of the fats of butter. Fats of other fatty acids are present and to these are due the flavor and odor of the butter. The most important of the other fats are the compounds of butyric, caproic, caprylic, and capric acid.

Oleomargarine butter is butter manufactured from the fats of beef and lard which also contains the fats of oleic, palmitic and stearic acid. Oleomargarine butter is, therefore, good butter and the prejudice against it is entirely unwarranted. Natural butter is, of course, liable to the same kinds of contamination as milk and hence may be the source of similar dangers.

Cheese—Cheese is the coagulated casein of milk pressed into forms and ripened by inoculation into it of various organisms (enzymes, molds, bacteria) which grow through it until limited by

the products of their own growth. It is the products of the growth of these organisms so inoculated into it which impart different flavors to the varieties of cheese.

Cheese should contain 50 per cent proteins (casein) and 30 to 35 per cent of milk fat.

Cheese may become accidentally infected with an unknown organism which is capable of producing a violently poisonous ptomaine called tyrotoxicon. This same ptomaine has been found responsible for many cases of poisoning from milk and ice cream. The poisonous symptoms are accompanied with the violent gastro-intestinal symptoms of vomiting, nausea, abdominal pains, diarrhea, and marked prostration.

Vegetable Foodstuffs—Vegetable foodstuffs may be divided into the following:

1. Farinaceous seeds which include—
   a. The cereals;
   b. The legumes.
2. Farinaceous preparations.
3. Fatty seeds (nuts).
4. Vegetable fats.
5. Fibers and roots.
6. Herbaceous articles (vegetables).
7. Fruits used as vegetables.
8. Fruits in the narrower sense.
9. Edible fungi.
10. Saccharine preparations.

The Cereals—The cereals include wheat, rye, barley, oats, corn, buckwheat, and rice. These all contain about:

10 per cent of moisture
12 per cent of proteins
1.5 to 6 per cent of fat
50 to 70 per cent of starch.

Wheat—The proteins of wheat are albumin, proteose, gliadin, and glutamin. The last two form 80 to 90 per cent of the proteins of wheat. They unite in the presence of water to form a paste called gluten, and the nearer the proportions of the gliadin to

— easily digested —

the glutamin to the ratio of 25 gliadin to 75 of glutamin, the better is the flour from the wheat for bread-making purposes. The carbohydrates in wheat are cellulose, sugar, dextrin, and a number of unimportant carbohydrates. The starch is in the form of granules .002 to .05 millimeters in diameter in which the starch is imprisoned in concentric rings of cellulose which must be ruptured by boiling in water before the starch is liberated. High grade and more thoroughly bolted flour is poorer in proteins and fats and richer in starch than the less thoroughly bolted flour. However, the unbolted flour is not necessarily more nutritious but contains rather more of the indigestible residue. This residue is somewhat more irritating to the gastro-intestinal tract and in virtue of this character it is believed to act more favorably in patients troubled with constipation than the purer high grade flours.

Macaroni—Macaroni is made from a special variety of wheat which yields much gluten. The best wheat for macaroni is obtained from Algeria or Russia. The American wheat is not rich enough in gluten and too rich in starch. The chief adulterations of wheat are magnesium carbonate, gypsum, chalk, alum, and nitric and nitrous acids, formed by nitrogen peroxid used for bleaching purposes. Adulterants are to be recognized by the microscope and the question whether flour has been bleached or not by the fact that the gasolin extract of unbleached flour is yellow.

Rye—The proteins of rye closely resemble those of wheat, but yield less gluten. Its nutritive value is about the same as that of wheat.

Barley—Barley yields no gluten. When it is deprived of its husks and polished, it is known as pearl barley. It is used chiefly in the manufacture of beer. In the manufacture of malt from barley, a peculiar product is formed which converts starch into sugar.

Oats—Oats are comparatively rich in vegetable fats and crude fiber. They contain 12 per cent of proteins, but only 58 per cent of starch. They yield no gluten but can be used to make very palatable cakes and cereals. They exert a mild laxative action, probably from their content of crude fiber.

Corn—From corn are made several food products. It is eaten from the cob or boiled after cutting from the cob.

Hominy—Hominy is corn after removing the hulls by soaking.

Samp—Samp is the whole kernel of corn minus the gum and the hull.

Indian meal is prepared by grinding the whole kernel and bolting more or less of the bran.

The proteins of corn include several globins, myosin, vitellin, and two special albumins and two zeins.

Rice—Rice constitutes the main article of the diet of one-third of the human race. It is usually sold in the form of polished rice, that is with the reddish cuticle removed. It has rather a low amount of both protein (7.50 per cent) and fat (40 per cent). It is rich in starch and is easily digested. It is best not to cook it by boiling, which removes some of the naturally deficient proteins. In preference it should be cooked by steaming.

Buckwheat—Buckwheat is the most expensive of the cereals and, therefore, most apt to be adulterated. Natural buckwheat contains 10 per cent of crude fiber, which is almost wholly removed by the milling in the conversion of buckwheat into flour.

Legumes—Include peas and beans, both string and lima beans and the soja bean and lentils. The main character of the legumes is the large percentage of proteins which they contain. The chief protein is legumin, a protein closely resembling casein.

The proteins in legumes are as follows:

Legumin	60.95	per	cent
Glutamin	30.65	"	"
Albumin	0.64	"	"
Gliadin	7.75	"	"

While most of the legumes have a high nutritional value, they are somewhat difficult of digestion and at least 1/3 to 1/5 is lost in the excreta. They contain considerable sulphur which may induce flatulency.

In general the legumes contain:

Water	10 to 15	per	cent
Proteins	23 to 25	"	"
Fat	1 to 2	"	"
Starch	45 to 55	"	"

Dried peas and beans lose much of their value by the prolonged soaking which is necessary and their flavor is not nearly so delicious.

Canned peas and beans contain much less nourishment. Canned peas contain only:

3.6 per cent of proteins
.2 " " of fats
9.8 " " of carbohydrates.

String beans, of course, contain only a small amount of nourishment. They have as follows:

2.3 per cent of proteins
.3 " " of fats
7.4 " " of carbohydrates.

The soja bean is remarkable for the high percentage of protein (33 per cent) and fat (17 per cent) which it contains. It only contains 30 per cent of starch.

Lentils are a most nutritious legume and their more general use should be encouraged. They contain:

25 per cent of proteins
53 " " of starch
but only 1.89 per cent of fats.

Farinaceous Preparations—Farinaceous preparations include sago which is the pith of certain palm stems, and the tapioca or the thick fleshy tuberous root of the manihot, and arrowroot which is a pure form of starch derived from the tuberous root of the maranta. These preparations are easily digested but are almost solely starchy foodstuffs.

Nuts—Nuts are rich in fats and oils and in consequence contain a high nutritive value, but they are not easily digested. Almonds, cocoanuts, walnuts, and peanuts contain 45 to 70 per cent of fats and 15 to 16 per cent of proteins. The cocoanut contains 7 per cent of sugar. The chestnut, which is not a true nut, contains little fat, 15 per cent of sugar, and 25 per cent of starch. It is, therefore, indigestible.

Tubers—Tubers include white potatoes, sweet potatoes, and artichokes. Both varieties of potatoes have relatively very little protein (2 per cent) and also in starch (18 to 27 per cent). Artichokes contain twice as much protein (4 per cent), no starch, but 15 per cent of sugar.

Roots—Roots include a whole group of foodstuffs, such as beets, carrots, oyster plants, parsnips, radishes, and turnips. They all contain:

80 to 90	per	cent	of water
1 to 1.5	"	"	of proteins
10 to 15	"	"	of carbohydrates
.1 to .5	"	"	of fats.

Herbaceous Vegetables—Among the herbaceous vegetables are asparagus, cabbage, cauliflower, sprouts, celery, lettuce, spinach, beet tops, dandelion, leeks, and onions. These contain:

90 per cent of water

1.5 to 2 per cent of proteins (sprouts contain 4.7 per cent)

3.0 to 5.0 per cent of carbohydrates (onions and dandelion contain 10 per cent)

.3 to .5 per cent of fats (asparagus contains 3.3 per cent)

They contain little of the essential foodstuffs but are valuable for their salts and laxative effects.

Fruit Vegetables—Fruit vegetables include tomatoes, cucumbers, squash, pumpkins, egg plants, and vegetable marrow. They all contain little nutritive value, about 90 per cent of water and less than 1 per cent of proteins.

Fruits—The fruits include apples, pears, peaches, apricots, plums, prunes, cherries, oranges, grapes, and melons. They contain:

80 to 85	per	cent	of water
.4 to 1	"	"	of protein (the majority less than 5 per cent)
5 to 10	per	cent	of sugar.

Though they possess little of nutritive foodstuffs, they are valuable alteratives, because of the rich contents of organic acids (about 1 per cent) and salts. They are slightly laxative.

Bananas and Figs—Bananas, plantains, and figs are the most nutritious fruits. They contain 2 per cent of proteins and 20 per cent of sugar; figs contain 4 per cent of proteins and 50 per cent of sugar.

Berries—The various berries, blackberries, cranberries, currants, gooseberries, huckleberries, mulberries, raspberries, strawberries, have all about:

85 per cent of water
5 to 10 per cent of sugar
0.5 per cent of proteins (strawberries 1.07 per cent)

Mushrooms—Mushrooms are composed chiefly of fiber. They contain 12 per cent of solids, of which nitrogenous compounds form a large proportion. This nitrogen, however, is chiefly in the amino acid form probably and, therefore, is not available to any large extent for assimilation. At least it is not known how many of the amino acids of the protein foodstuffs are contained in mushrooms. The high nutritive value formerly attributed to mushrooms is probably not to be obtained from them.

TEA, COFFEE, AND COCOA

Tea—The different varieties of tea depend chiefly upon the age of the leaves when gathered and the method of drying and preparing them. The choicest teas are the youngest terminal leaves of the plants.

Green teas are obtained from young plants roasted soon after gathering. Black teas are the coarser older leaves dried for ½ a day and then rolled and roasted. Tea contains:

21.22	per	cent	of nitrogenous substances
.67	"	"	of volatile oil
1.35	"	"	of thein
3.62	"	"	of fat
7.13	"	"	of gum dextrin
12.36	"	"	of tannin
16.75	"	"	of extractives
20.36	"	"	of fiber

The important principle is thein, which produces a definite physiological action upon the body. In the preparation of tea, the method of drawing is all-important. The first drawing with hot water makes the most delicious beverage and contains the least tannin. Steeped or boiled tea contains much tannin which both imparts a bitter taste and increases its indigestibility.

Coffee—The world's annual consumption of coffee amounts to 900,000 tons and of this the United States consumes one-third. In

coffee the caffein, which is the same as thein, is intimately associated with tannin. When toasted at 200° C., the two are disassociated. The sugar is changed to caramel and certain aromatic principles are developed. The roasting of the coffee must be carefully done, otherwise the flavor of the coffee will be impaired by the draining off of certain of the isolated principles. Weight by weight, coffee really contains less thein than tea. Coffee contains .64 to 2.21 per cent; tea contains 1.36 to 3.09 per cent.

Coffee contains as follows:

.64 to 2.21 per cent of thein
12 per cent of fat
40 " " of fiber
and traces of sugar and gum.

The question of the relative physiological effect produced by coffee and tea is not to be decided by the relative amounts of thein contained by each. So much depends on the strength of the drawn tea or coffee and the quantity consumed that the relative amounts of thein in each is a guide of small value. Both, however, produce a definite physiological action. Each individual must be his own guide as to the quantity of each of the beverages which he drinks. It is certain, however, that the desirable limit is easily overstepped and that as a consequence many individuals suffer a train of unpleasant symptoms both neurotic and digestive in nature, which seriously handicaps their efficiency.

Coffee is easily and frequently adulterated. Almost all the adulterated varieties contain starch which is easily detected by the iodin test. Coffee itself contains no starch. The preparation known as De Kafa contains about 1/5 of the usual amount of caffein.

Cocoa—Cocoa is obtained from the bean of the cocoa plant. This bean is one of 4 to 10 beans about the size of almonds occurring in 5 rows in a pod which measures 1 foot long by ½ foot wide.

When ripe, the pod is gathered and allowed to ferment for 24 hours or more. They are then opened and the seeds removed and allowed to ferment longer in holes or earthenware vessels. The seeds are then dried.

For the market the seeds must be carefully cleansed and roasted. During the roasting, the husks come off and the seeds are crushed

slightly and then freed from the husks and hardened (germs). They are then ground into a paste and allowed to harden into cakes. These cakes are chocolate.

To prepare cocoa some of the oil of the chocolate is removed by hydraulic pressure, and the residue is passed through a very fine sieve.

Unlike tea and coffee, cocoa is relatively very nutritious. Its active principle is theobromin, which closely resembles thein.

Cocoa contains:

3.63	per	cent.	of water
13.49	"	"	of proteins
49.32	"	"	of fat
13.25	"	"	of starch
13.18	"	"	of extractives
3.65	"	"	of fiber
3.48	"	"	of ash.

The amount of the theobromin averages 1.50 per cent. It is less stimulating and more diuretic than thein. Compared to tea and coffee in the usual strengths in which these beverages are taken, cocoa is far weaker in its physiological action and a much more wholesome beverage.

The husks of the cocoa bean make a cheaper but, nevertheless, a very wholesome product.

The Preservation of Foods—The preservation of food may be accomplished by several methods.

Cold—The best preservative for food is cold slightly above the freezing point of water. Meat, fish, and eggs, etc., will all keep in dry air at this temperature. Care should be taken that the temperature is uniform. Alternate thawing and freezing does impair the quality of the food. The production of the cold by the ammonia process is good provided that the food is in air-tight spaces in order that the ammonia does not penetrate into it. Packing in ice only answers for a short period.

Drying—Drying is efficient according to its thoroughness. It may be used for meats and vegetables. It does not insure safety against parasites and impairs the flavor and the digestibility of the food.

Salting—Salting also impairs the flavor and digestibility of the food.

Smoking—In smoking, some of the creosote and other substances of the wood consumed penetrates the food; or the meat, in the quick process, is brushed over, or dipped in pyroligneous acid at intervals and dried in air. It seriously impairs the value of the food in its digestibility and flavor.

Canning—Canning is an excellent method of preserving food. The food is packed in cans and then sealed except for a very small hole. The can and its contents are then raised to the boiling point of water or higher for 1 hour and the hole closed. They are then reheated. There is no good evidence that the action of the food on the metal corrodes it sufficiently to produce the slightest harm to the individual eating its contents. Canned goods have stood the test for 5 to 10 years in many instances, and have always been found in good condition.

Chemical Preservatives—The use of chemical preservatives includes the use of boric acid, borax 1 to 500 or 1,000, salicylic acid 1 to 1,000, sodium sulphate 20 per cent, formaldehyd 1 to 5,000, hydrogen peroxid 1 to 1,000, all of which are not infrequently used. And in addition some 35 other preservatives. All of them are to be condemned from a standpoint of altering the food, its digestibility, and many of them become indirectly irritating to the stomach.

Contamination of Food by Metals—Food is often contaminated by various metals. The various acids or alkalis in the food being responsible for dissolving off a certain quantity of the metal.

Lead—Of all the metals, lead is the most important. Tin foil may contain lead in quantities varying from traces up to 89 per cent. The metallic caps for preserving fruit may contain 93.5 per cent of lead. The contents of sealed bottles may yield as much as 1.05 milligrams. Lead is commonly dissolved by preparations containing carbon dioxid, tartaric or citric acid. It may, therefore, be present in baking powder, in summer drinks or in beer. The highest amount found in such preparations was .037 per cent. Canned foods are now not likely to contain lead. Unquestionably the daily ingestion of small quantities of lead is dangerous. It is illustrated by the lead colic not infrequently met with in painters who are not careful to eat with well-washed hands. As regards

lead in food from other sources, acid drinks in bottles with lead stoppers are to be particularly avoided, or beer transported through lead pipes.

Copper—Copper may be picked up from copper cooking vessels. Thirty-six and eight-tenths milligrams of copper were found to the liter of broth which stood for 24 hours in copper vessels, and 21 milligrams in 100 cubic centimeters of rancid fat standing for two weeks.

Copper is sometimes used as a component of those preparations employed for greening vegetables. Thirty-nine milligrams of copper have been taken daily for fifty days without harm. Its complete excretion may occupy five months. Copper appears to be a normal constituent of certain vegetables. Little danger can come from it when taken in small doses. For a considerable length of time it is completely excreted. Probably larger doses are not absorbed.

Zinc—Zinc was formerly a contamination of canned goods and came from the flux used in the soldering of the can. At present an improved method with another flux is used. Acid substances may extract zinc from galvanized iron. It has been a rather common contamination of dried apples which have picked it up from the rocks on which they have lain; .03-.49 milligram to the kilogram has been found. In these amounts it has no sanitary importance.

Nickel—Nickel has been used in place of copper for greening peas in the proportion of ¼ of a gram to a kilogram of peas. It is said to be given off from nickel dishes in which food is cooked. Traces up to 12.9 milligrams have been found in 100 grams of food. There is no evidence that these amounts can produce injury.

Tin—Contamination with traces of tin is common but so far as it is known it seems harmless.

AIR

Composition—Air contains about 21 per cent of oxygen and 78 to 79 of nitrogen, traces of hydrogen (.015 per cent) and argon 75 per cent, varying quantities of ozone and ammonia, and, though present in very small quantities, but yet of extreme importance, .03 per cent of carbon dioxid.

The nitrogen simply dilutes the oxygen in the air. It and argon are inert. Although much of hygienic importance has been claimed for ozone, and for the value of inhaling air containing ozone, and for the purifying effects of ozone in air, yet no practical evidence exists that it possesses any significance. Ozone is very irritating to mucous membranes. If inhaled in proportions of 1:240 it will quickly produce death in animals.

All life, directly or indirectly, depends upon the oxygen and carbon dioxid in the air. The oxygen is consumed by plants and animals alike and used for the production of energy.

Man inhales 7 lbs. of oxygen in 24 hours. Of this the lung absorbs 2 lbs.

The Production of Carbon Dioxid—From the carbon dioxid in the air the plants build up the organic compounds of carbon which form the foodstuffs of animal life. The chief sources of carbon dioxid in the air are respiration, fermentation, and compression. A normal animal exhales 20 liters of carbon dioxid per hour.

Every ton of coal consumed yields 67,000 cubic feet of carbon dioxid. Every cubic foot of coal gas consumed yields twice its value of carbon dioxid. From all sources probably 5,000 million tons of carbon dioxid are added yearly to the atmosphere. The ocean contains about ten times the amount of that in the atmosphere.

The forces tending to withdraw carbon dioxid are doubtless far greater than those contributing it. Untold quantities are locked up yearly as insoluble carbonates by the coral- and shell-producing invertebrates of the sea. The quantities washed down by rain unite with the alkali earth metals and become insoluble. The total respiratory contributions of carbon dioxid are small as compared to the chlorophylian function of plants.

An acre of land withdraws 4½ tons and returns 3¼ tons. The remaining ton is, of course, at some future date in the returned process of combustion of the substances, formed from the retained carbon dioxid.

The Possibilities of Varying the Percentage of Carbon Dioxid in the Respired Air—An increase of the normal tension of carbon dioxid in the blood is accompanied by alterations of some of the most important physiological functions of the body and is not tolerated until the compensating mechanism is overpowered. It

is possible for the compensating mechanism to keep the blood tension of carbon dioxid normal (40 millimeters of Hg.) in the presence of considerable variations in the amount of carbon dioxid in the external atmosphere. The percentage of carbon dioxid in the air may be increased to 5 per cent without seriously altering the percentage in the alveolar air, though to keep this, constant respiration will be increased to 20 a minute. It is generally held that carbon dioxid is not harmful when it is increased to 20 parts per 10,000 or 0.2 per cent. In fact, many instances are known in which the carbon dioxid has been increased to 43.20 (.4 per cent) and even 100 parts (1 per cent) per 10,000 without ill effects. A room generally does not begin to feel close until the carbon dioxid content reaches 10 parts per 10,000. The permissible high limits are generally regarded as 6 or 7 parts per 10,000. When the quantity of carbon dioxid reaches 15 parts per 10,000, the occupants of the room may begin to suffer from headache.

It is certain that the carbon dioxid itself is not the cause of this headache or the depressed and uncomfortable sensations which accompany high percentages of carbon dioxid in the air breathed. The ill effects have been attributed to poisonous organic matter which is exhaled from the breath and from the skin of the individuals crowded together and which is responsible for the increase of carbon dioxid. The increase of carbon dioxid from 6 to 7 parts per 10,000 is adopted as a guide not so much to the permissible limits of carbon dioxid in the air as because, accompanying any increase of carbon dioxid in the air the air becomes objectionable for other reasons.

Explanation of the Toxic Effect of a Close Atmosphere—It has been said that the various other objectionable features are the various organic exhalations, but no toxic substances of this nature have ever been isolated from vitiated air. According to the latest view, the harmful effects of deficient ventilation are due rather to the increased temperature and moisture of the air which has been contaminated by the increase of the carbon dioxid content to 6 or 7 per cent. In order to replace the air in a room containing 1,000 cu. ft., at a sufficient rate to keep the carbon dioxid down to 0.07 per cent, 2,000 cubic feet of fresh air should be supplied for each individual occupying the room every hour, inasmuch as each individual gives off .6 cubic feet of carbon dioxid every hour.

Air almost always contains a certain percentage of water. Water vapor is lighter than air and is very unequally diffused. Every adult may give off 4 lbs. of water from the skin and lungs during the 24 hours. This source of increase of moisture in the air is an important reason for the toxic effect of overcrowded rooms.

Function and Effects of the Water in the Atmosphere—An enormous quantity of water is added to the atmosphere by plant life. Each healthy tree contributes a great deal. Every plant contributes 250 to 400 times the weight of the dry organic matter added to the plant at the same time. At 0° C. air takes up 1/160 of its volume of water and at each increase of 15° C. it takes up twice as much more.

The quantity of moisture in the air greatly influences the rate of elimination of water from the body. At 15° C., in moist air, the daily elimination of water is 216 grams. When the air is dry, at the same temperature, the elimination is 871 grams. The water vapor in the air performs a very useful purpose, preventing the rapid cooling of the earth at night.

In hot air saturated with moisture, the evaporation of the perspiration is slow and the radiation of heat from the body is slow. It is for this reason that the heat becomes oppressive in damp weather. Saturation, however, in cold weather has almost as great an influence on bodily comfort. The water vapor makes the air a better conductor of heat and for this reason one feels the cold intensely when the air is damp in the winter time. When this is the case we are accustomed to say that it is cold and penetrating. On the other hand in the coldest weather when the air is dry, no particular hardship is experienced.

Dust and Bacteria in the Atmosphere—Dust, organic and inorganic, of all dimensions is ubiquitous in the air. Microörganisms are very abundant in the air of inhabited rooms and towns. At high altitudes, 6,300 feet above sea level, no microörganisms are found. Over the ocean 120 miles from land, the air is free from organisms and at 90 miles out it is comparatively free from microorganisms. In London it is calculated that an individual inhales 4,000,000 bacteria per hour. This number, however, is probably very large and even so corresponds only to the number of bacteria in 4 cubic centimeters of milk. At Montsouris the average number

of bacteria, in an investigation which extended over a period of 6 years, was only 455 per cubic meter. During the same period the number in the air in the center of Paris was only 3,910. While the number of bacteria in the air appears to be high, it must be remembered that the vast majority are not pathogenic.

Nevertheless, in the vicinity of the sick, sufficient pathogenic bacteria may float in the air to constitute a real source of danger. Of no bacterium is this more true than of the *bacillus* of tuberculosis.

The dust in the air, however, serves a very useful purpose. It is very hydroscopic, attracting and holding on to the last vestige of water most tenaciously. Without it the vapor of the clouds would not condense and there would be no rain or fog, but the vapor would simply condense on the surface of the earth and upon those objects upon it.

Gases in the Atmosphere—Of the gases which may contaminate air, there are hydrogen sulphid, sulphuric acid, hydrochloric acid, carbon bisulphid, marsh gas, and carbon monoxid. None of these gases are of much importance except carbon monoxid. It gains entrance to the air chiefly from leaky gas pipes. It has been calculated that in Paris the annual loss of illuminating gas was 15,000,000 cubic meters.

A smaller amount than 0.25 per cent by volume in the air will cause poisoning, and 1 per cent is rapidly fatal. There have been cases of the poisoning of adults from the aspiration of gas into the cellar of a dwelling, 100 feet from a leak in the gas main.

Contamination of the Air by Sewage—Sewage is a frequently alleged source of impurity of air and the contaminated air from sewers is called sewer gas. Its composition depends upon the rate of generation of the gases produced by decomposition of the sewage and upon the completeness of the ventilation of the sewer. It may be quite pure or contain 10 to 30 volumes of carbon dioxid in 10,000. In London there are 51 volumes and in Paris 340. Ten to 30 volumes is not, therefore, an unusual amount. Besides carbon dioxid there are traces of hydrogen sulphid, marsh gas, and compounds of ammonia. Sewer gas also contains bacteria and vegetable débris. Sewage itself is, of course, full of bacteria, 20,000 to 200,000 *coli communis* to the cubic centimeter are frequently present and it is alleged that the rise and fall of water in the sewer leaves

many bacteria high and dry. The bursting of the gaseous bubbles in the sewage and the splashing of the sewage as it passes along its conduits are causes for the contamination of air with many bacteria. Nevertheless, it is true that the sewer gas is bacteriologically purer than the air within the rooms of schools and dwellings. For instance, practically no *colon bacilli* are found in the sewer gas. Moreover, of the bacteria found in the sewer gas, few are of the liquefying varieties.

Unquestionably, the chief reason for excluding sewer gas from dwellings is because of its power to render the air within them disagreeable from an esthetic standpoint. The best authorities are agreed that sewer gas is not capable of transmitting typhoid bacilli and that bacteria are not given off in any significant numbers from the surface of sewage.

It is true that the *bacillus prodigiosus* has been recovered on plates held 10 feet above the traps of inoculated drainage systems and has penetrated all parts of the house in open connection, up to 50 feet in height; yet the amount of air infection, even under extreme conditions, is so slight that one would scarcely expect the general air of sewers and house-drains to be appreciably affected under normal conditions.

Moreover, human beings spending much of their time actually working in sewers are, as a rule, quite healthy and certainly they are not particularly susceptible to infections traceable to sewers.

The Sole Source of Dangerous Contamination to the Air— Under the normal conditions usually met with, we may dismiss in a word all the various means by which it is possible for air to be contaminated from either individuals or sewers, with one exception, as unimportant. This exception is the infection of the air by diseased individuals with specific pathogenic bacteria. It is for this reason chiefly that overcrowding is always associated with ill health and an increase of the air space allowed to each individual has always been associated with a decrease in illness. At one time, for instance, the death-rate in the English Army from phthisis alone was 11.9 persons per 1,000. The introduction of more efficient ventilation and increase of average air space caused an immediate improvement, a reduction of this death-rate to 1.2 per 1,000. The same facts are true of animals left in captivity. The immediate effects of overcrowding are discomfort, oppression, headache, dizzi-

— Consumption

ness, faintness, and nausea. Continued exposure causes pallor, languor, anemia, skin troubles, loss of appetite and in consequence a diminished resistance to disease. As has been explained, these symptoms are dependent chiefly upon the increased temperature and moisture in overcrowded spaces and upon a diminution of oxygen, whenever such diminution occurs, but not upon the increase of carbon dioxid or the collection of any organic poisonous matters given off from the body, called in a vague manner crowd poisons and consisting of epithelium, constituents of sweat (butyric, capric, capronic, caprylic acids, lactate, butyrate and other salts of ammonia) and the volatile matter from foul mouths in which decayed teeth are present and from individuals with poor digestive functions, and the excrementitious matters deposited on unclean clothing, also poisonous matters in the breath.

There can be no question that the air transports bacteria and wherever individuals who have harbored pathogenic bacteria have been living, the air will transport such bacteria and becomes a real source of infection. The possibilities of the transport of bacteria through the air is directly proportional to the quantity of dust which it contains. Dust is very hydroscopic and will hold tenaciously a certain quantity of water. The protection which dust affords to bacteria both in itself and in virtue of its hydroscopic character is an important factor to the transportation of these bacteria.

Tubercle Bacilli in the Air—The bacillus of tuberculosis has been found in an active state in a room 1 year after the death of its occupant. This bacillus has been found in 147 samples of dust collected from hospitals.

In 76 per cent of the cases examined, *tubercle bacilli* were found in the droplets coughed out by tubercular patients. The smallest number of bacilli that were found were 4 and in 1/3 of the cases they were numerous. Dust taken from places likely to be infected were injected into 81 guinea-pigs, a large number of these became infected and died. The dust from the most suspicious rooms was the most fatal, while those pigs inoculated with dust from buildings in which there had been no tubercular inhabitants, did not become infected with tuberculosis.

Typhoid Fever in the Air—Opinions vary as to the danger of contracting typhoid fever from the dust of rooms in which typhoid

pertaining to the face

patients have been confined. The typhoid bacillus cannot stand drying while the *tubercle bacillus* can stand relatively very complete drying for long periods.

Diphtheria—The diphtheria bacillus, on the other hand, will survive drying for relatively long periods. It is abundant in the mouth and nose of those ill with diphtheria and may persist in a virulent state for long periods after apparent recovery. The dust in the vicinity of those ill with diphtheria becomes contaminated with diphtheria and is a source of danger to others.

Streptococcus—The streptococcus of erysipelas, pneumonia and pyogenic infections resists drying to a somewhat unusual degree so that transmission through the air becomes extremely probable.

Diplococcus—The diplococci also resist drying. The diplococcus of epidemic cerebrospinal meningitis, dried in a handkerchief, has been found to be capable of causing infection 6 weeks after use of the handkerchief by the patient. It is believed to present the greatest resistance to drying.

Cholera—There is not much danger of contracting cholera from dust. They live only a short time when mixed with dry dust.

Dysentery—The organisms responsible for the summer infantile diarrheas of children will survive for relatively long periods and dust and dirty air are important means of spreading these diseases in the cities. In fact, the frequency of these diseases bears an inverse ratio to the amount of rainfall.

In general, however, foggy weather always increases the dust evil, for it supplies a certain quota of moisture to the dust and prevents the absolute drying out of the bacteria. Respiratory diseases, particularly, show an increase during foggy weather.

Smoke—Smoke must be included as an offensive constituent of the atmosphere. It is also objectionable because of its irritating, corrosive, and disfiguring actions, and because of its influence in shutting out the sunlight. The use of methods of consuming smoke in furnaces should be encouraged; moreover, this use is an economy. The best method is the one brought to the attention of the State Department by Consul-General Mason. This process consists of distributing heated and slightly compressed air through hollow grate bars to the whole lower surface of the furnace. The combustion is completed by this method; and inasmuch as the low-grade coals can be used, additional saving can be made.

SOIL

Composition and Classification—Soil is a mixture of minerals, sand, or clay with organic material. Soil is divided into:

1. Superficial soil.
2. Subsoil.

Superficial soil is classified as:

1. *Sandy*—Sandy soil is that of which 4/5 is composed of sand.

2. *Clay*—Clay is composed largely of silicate of aluminum, which is very cohesive. The plasticity of clay is due to a small proportion of silicate of aluminum. The addition of one-one-hundredth part of caustic lime greatly modifies this plasticity. Clay is very impermeable to water and dries with great slowness.

Loams—Loams are mixtures of sandy clays and humus. They partake, therefore, of the characters of the clay and of the humus. When the clay predominates, they are termed heavy, the word heavy referring to the ease with which they are molded in agriculture.

Marls—Marls are mixtures of sands, clays, amorphous calcium carbonate and often potash or phosphates from the fauna and flora of the sea.

Humus—Humus is a term used to designate the product of vegetable decomposition in the various intermediate stages of the process. It is necessarily of very complex composition. Its principal characteristic is its high content of nitrogen.

Peat—Peat or muck contains a high amount of humus. Peat results from incomplete decay under water and is compact and fibrous. Inasmuch as the decay is incomplete, the peat varies in its compactness and fibrous character. It reduces to a powder when dry.

Constituents of the Soil—The chief constituent of the soil is silicon, the next is aluminum. The silicate of aluminum forms two-thirds of the earth's crust. Lime and magnesium are next in abundance. They occur chiefly as the carbonates. They are essential for plant life and hence to animal life. Lime exerts a marked influence in the conditions of the soil which favor the processes of nitrifica-

not admitting passage -

tion. Lime and magnesium also exist as phosphates and sulphates.

Iron is ubiquitous in the soil and important for all life. Manganese comes next in amount and is comparatively unimportant. Chlorin is not a large constituent of the soil. It occurs as the sodium, potassium, and magnesium salt. In unpolluted soil it is seldom present in quantities exceeding 1:10,000. Sulphur is most important to plant life. It occurs chiefly as sulphate or sulphide of calcium. Phosphorus is essential for plant growth. It is widely distributed in small amounts as phosphate of lime, magnesium, iron, and alumina, sodium and potassium, and chiefly as insoluble silicates and, in small amounts, as chlorids. Nitrogen exists in the soil in three forms, as follows:

1. Proteins.
2. Ammonia and its salts.
3. Nitric acid and nitrates.

In the average soils it is present in amounts of less than 1 per cent. In very rich soils it may be present in amounts of from 4 to 6 per cent. The nitrogen of the soils is not available for most plant life in any form, except the oxidized forms of ammonia, the nitrates.

The change of proteins and organic combinations of nitrogens to ammonia, and then into nitrates, is accomplished by various varieties of bacteria whose presence in the soil is really essential to plant life.

Porosity—Porosity is an important property of the soil. It is the sum total of the interstitial spaces of the soil. The amount of porosity of the soil depends not so much upon the size of the particles as upon their relative arrangement with each other. Even rocks have some porosity. Sand usually possesses 30 per cent and most soils at least 40 per cent.

Permeability in contrast to porosity depends upon the size of the individual spaces between the particles. The amount of moisture present in the soil greatly influences the permeability of the soil. It also depends upon the degree with which the soil is wetted from beneath the latter in contrast to wetting from the surface producing little effect on the permeability of the superficient layers. A freezing temperature also diminishes the permeability of water-laden soil.

The Capacity of Soil for Water—The capacity of soil for water

depends on a porosity of such a character that the size of the individual spaces is capable of exerting capillary attraction. A soil rich in organic matter possesses great power of holding water. Humus can hold 10 times its weight of water. Soils poor in clay and also poor in humus permit the passage of water in the shortest time. Clay and humus certainly contain water and the presence of much organic matter in the soil assists in the retention of water. The capillarity of the soil is very important for vegetable growth. At the same time it favors an increase of moisture in the air.

The Temperature of the Soil—The temperature of the soil depends chiefly upon the heat of the sun, and this in turn upon the obliquity of the sun's rays. Any heat derived from chemical changes in the soil is an unimportant quantity. The annual variation in the temperature of the soil diminishes as the distance from the surface of the ground increases. At a depth of 15 feet the annual variation in the temperature is less than 10° F., and between 50 and 80 feet the temperature is constant the year round.

A dark soil absorbs more heat than a white one which reflects it, although from the very fact that the white soil reflects it, it may feel hotter than the dark soil. There may be, for instance, an actual difference of 25° F. in the temperature of white sand and black humus exposed to the sun's rays, side by side.

Rocks, sand, and mineral matter are better heat conductors than water. Organic matter is a poor heat conductor. The specific heat of ordinary soils, i.e., the amount required to raise their temperature through 1° C., is 1/5 to ¼ of that of water.

The comparatively high specific heat of water causes it, therefore, to profoundly modify the temperature of the soil. Soil retains its heat in proportion to the amount of water which it contains. and loses it in proportion to the rapidity of evaporation, a process which in itself is accompanied at the expense of heat. The warm rain of Spring displaces the colder water of the soil and warms and preserves the heat of the soil.

Chemical Changes in the Soil and Mixing Forces—The chemical changes transpiring in the soil depend largely upon the bacterial life and proceed best at a temperature varying between 53° and 131° F. At 98° F. it proceeds most extensively near the surface and requires the presence of air. It practically ceases at a depth of more than 3 feet.

The various chemical changes in the soil and the properties of the soil are modified by the action of earth worms in the soil. These live on half-decayed leaves and vegetable matter. This they pull into their holes; it is eaten and passed out of their bodies again. They also excrete a humus acid which disintegrates rocks. They, therefore, play an important part in the disintegration of the soil, in the transporting and mixing of the nitrogen with the soil, and bringing to the surface the constituents of the deeper layers of the superficial soil.

The castings of earth worms contain .018 per cent of ammonia. It is estimated that 10 tons of earth pass through their bodies every year per acre. In the course of ten years their castings would form a layer .83 to 2.2 inches thick, according to the soil and the air circulating through the soil. The soil is much richer in carbon dioxid than the atmosphere.

The Carbon Dioxid of the Soil—The amount of carbon dioxid increases with the depth, up to certain limits.

The amounts at three different stations were as follows:

	1st station	2nd station	3rd station
1 meter deep	4.8	13.7	18.1
2 " "	6.6	14.3	28.4
3 " "	..	20.1	..
4 " "	28.7	..	36.5

The carbon dioxid is least in the cold months and greatest in warm months. The fluctuations depend upon the rainfall and the wind and the rise and fall of the water of the subsoil and the differences of the atmospheric pressure and the temperature.

The Air and the Soil—There is throughout the soil a constant circulation of the soil air. This depends upon the wind over the surface which aspirates the air beneath the surface of the soil, and upon the perflation of the soil by the wind, a force due to the direct impact of the wind upon the ground and particularly in uneven country.

Water in the Soil—Soil possesses different hydroscopic properties. The hydroscopic power of dust has already been mentioned. Soil rich in humus attracts and adheres to water very tenaciously. The dust, for instance, of country roads which is apparently dry may yield 1/10 of its weight in water.

[The flowing hair in to a [illegible] (for drawing purposes)]

The largest quantities of water are situated at a depth from the surface of the soil, but due to the power of capillary attraction there is a constant passage of the water upwards. The higher the temperature the greater the diminution in velocity and ease of movement from below upwards.

Dissolved substances influence the rate of this upward movement of water through the soil. The nitrates increase the movement and the chlorids and sulphate diminish it. The presence, however, of organic matter greatly diminishes the rate of movement of the water through the soil.

Due to the baking action of the sun, the capillary tubes in the surface of the ground become transformed into more or less permanent tubes, and the formation of such tubes greatly favors the evaporation of the water from the surface, and consequently the drying of the superficial layers of the soil. Any breaking up of the surface tubes, such as the harrowing of the earth, preserves the supply of ground water.

Ground Water—By gravitation all water falling upon the surface of the earth sinks through the earth at a rate depending upon the permeability of the soil, until it reaches an impermeable stratum. Over this stratum it collects, extending upwards until it fills all the pores between the grains of the soil for a distance which is proportionate to the quantity of water. This layer of water is called the subsoil or ground water and the zone between its upper level and the air-filled interstices of the soil is called the groundwater level. There may be a succession of the impermeable strata, each separating layers of water, which becomes ground water at some distant places where the two imprisoning layers approach the surface. Clay is positively impermeable to water, but may, nevertheless, transmit its water to a layer holding water and with which it is in immediate contact. Rocks differ much in their impermeability, some may contain as much as 1/3 of their weight in water. Rocks are also often fissured and seamed and thus through their crevices transmit water.

The ground water is in constant motion both laterally and vertically. The lateral movement depends much on the configuration of the land and the direction of the impenetrable stratum, the rainfall and the snow. It is generally in the direction of the nearest large body of water, either the sea, or a lake, or a river. In

Munich the rate is fifteen feet daily and at Berlin it is very slight. The principal source of the ground water is the rainfall, which most influences its rise and fall.

The Consumption of Ground Water—The loss of the soil water by evaporation is greatly increased by vegetation. Vast quantities of water are absorbed by the roots of plants and passed by capillary attraction to the leaves, from the surface of which by transpiration it passes into the air of the atmosphere. The oak evaporates more than 8 times the rainfall on the surface of the ground which it occupies. The roots of wheat penetrate 8 feet below the surface.

1	acre	of	wheat	exhales	409,832	lbs.	of	water	during	8 mos.
"	"	"	clover	"	1,096,234	"	"	"	"	" "
"	"	"	sunflowers	"	12,585,994	"	"	"	"	" "
"	"	"	cabbage	"	5,049,194	"	"	"	"	" "
"	"	"	grapes	"	730,733	"	"	"	"	" "
"	"	"	hops	"	4,445,021	"	"	"	"	" "

Vegetation in the forests prevents the surface flow and increases the local retention of all the water of the rainfall and, although it exhales much water, it also prevents the waste of water. The growth in the forests also increases the penetrability of the soil for water. At least 4/5 of the rainfall is saved in the forests. The forests also prevent excessive changes of temperature which would otherwise increase the evaporation from the surface.

Pollution of the Soil—The soil becomes dangerous to the health when it becomes polluted by the discharges from human beings, or from the dead bodies of human beings or animals. There are many forces at work in the soil which will cause the disappearance of dead bodies, but much depends upon the nature of the soil. In the average soil bodies will disappear in a few years. In certain clays dead bodies will not disappear for two centuries. Bodies interred in loose, sandy, well drained, and ventilated soil rapidly become inoffensive. Those interred in compact and wet soil are slimy and very offensive and present a loathsome mass of rottenness.

The Purifying Forces in the Soil—The earth possesses great absorptive power for odors. This is illustrated by the absorption of gas from leaky gas mains. It exerts the same purifying action on substances in solution. From water it rapidly removes odors,

colors, and various other impurities. The finer the grain of the soil, the greater the purifying actions. The chief agent in the destruction of organic matter is bacterial action. There are few bacteria in the soil below a depth of 12 feet. Most of the bacteria are of the saprophytic varieties. Pathogenic bacteria are present as a consequence of the pollution of the soil by sick individuals who contribute specific organisms, or by the bodies of individuals who have died of specific diseases. Pathogenic bacteria so finding access to the soil do not find conditions favorable for a long-continued existence therein, although there is much variation among different species of bacteria in this particular. The majority of pathogenic bacteria cannot thrive in the presence of saprophytes. In the presence of the *bacillus cadaveris sporogenes* all pathogenic bacteria remaining in the dead body are destroyed. Two species of pathogenic bacteria are very widely found in the soil. They are the bacilli of tetanus and malignant edema. Both of these organisms, however, are spore-formers and, though widely distributed, even these do not find conditions in the soil favorable to growth.

The Relation of the Ground Water to the Preservation of Pathogenic Bacteria in the Soil—The height of the ground-water level, or in other words the amount of water in the soil, has much to do with the health of the locality. When the ground water is only 5 to 10 feet of the surface, conditions are far more healthy. It has always been found that ditching and the introduction of underground drainage have been followed by salubrity.

The Relation of Pollution of the Soil to Tuberculosis—A direct connection has always existed between the soil dampness and tuberculosis. The disease is comparatively rare in parts of the earth where the soil is dry. The explanation is, doubtless, not to be found in a single factor. Unquestionably a damp soil favors the preservation of bacilli in the dust and also has a direct bearing upon the excitation of the acute inflammations predisposing to pulmonary tuberculosis.

The Relation of the Dampness of the Soil to Typhoid Fever—Typhoid fever is very directly associated with the height of the ground water and the dampness of the soil. Typhoid bacilli implanted upon the surface of damp soil multiplied there and were found 130 days afterwards. Where they had been planted 18 inches below the surface they were actually found upon the sur-

– healthfulness

face of the soil. Later in the winter they could not be recovered from inoculated areas, but in the Spring they were again recovered by moistening the earth with sterile broth. Typhoid bacilli will live for months when incompletely dried, but they will not stand complete drying for longer than fifteen days, although a few days' drying does not impair their vitality. The hydroscopic properties of dust already referred to are important in this connection.

The Relation of Virgin Soil to the Preservation of Pathogenic Bacteria in the Soil—Unpolluted virgin soil appears to possess properties which are inimical to typhoid fever, regardless of the amount of organic matter of vegetable origin, while specimens of soil containing organic matter of animal origin favors the preservation of typhoid bacilli. They appear to thrive equally well when kept at 37° F. as at 98° F. In one sterilized polluted soil, the organism was active after 456 days, even after thorough drying and pulverization.

In Munich at the time that the city was honeycombed with cesspools, typhoid fever was extensive and endemic throughout the city. When the cesspools became largely replaced with a sewerage system, there was an immediate drop in the frequency of typhoid fever, even though the water supply of the city was not changed.

The Relation of Specific Soil Bacteria to the Destruction of Pathogenic Bacteria in the Soil—Within certain soils, there are species of bacteria which destroy the typhoid bacilli. Implantation of these species with the typhoid bacilli result in the disappearance of the typhoid, though similar controls, the implantation of the typhoid bacilli with other species, produced no effect upon the vitality of the typhoid. In unsterilized soils containing bacteria inimical to typhoid, the vitality of the typhoid lasted only 12 days. Typhoid bacilli have been recovered after spreading the contents of a cesspool upon a clay soil into which the stools of a typhoid patient had been discharged five months previously. Even the exposure of the clay for 15 days during the winter had failed to destroy the bacilli. The evolution of heat due to the chemical changes in compost heaps exert a considerable effect on typhoid and cholera, destroying them generally within a week, though under the same conditions tubercle bacilli remained virulent for months.

advance –

There have been many places in towns and country districts, where typhoid has been unknown until the introduction of a single sporadic case, after which other cases developed from time to time. Moreover, in the country, where the inhabitants do not travel far from their own farms, single cases of typhoid fever will appear in the same household at intervals of a year or longer.

Cholera—Cholera is not a soil disease. In times of its greatest prevalence, it has never been found in the soil. Under favorable conditions it will live for short periods of time but under the natural conditions it dies out quickly.

Bubonic Plague—Bubonic plague is also not a soil disease. It appears to be entirely communicated by fleas, especially the common rat flea (*pulex pallidus cerato phyllus fasciatus*) to which mice, rats and other rodents, such as squirrels, may serve as common hosts.

Diphtheria—Statistics have not demonstrated with regularity that the prevalence of diphtheria is proportional to the dampness of the soil, nor that it is more common when the soil-water level is high. The greatest and most extensive epidemics have occurred when there have been four or five consecutive dry years. The epidemic started near the beginning or end of the period. Dampness of the atmosphere, associated as it is with dampness of the soil, predisposes individuals susceptible to diphtheria to throat inflammation, which makes them fit subjects to contract diphtheria.

There is no proof that diphtheria bacilli retain their vitality long in the soil. After intensive inoculation they have been recovered from the infected spots for short periods, but according to statistics they have never been found in soils other than those intentionally inoculated.

An epidemic of diphtheria never originates in the towns and countries following a series of years in which the rainfall is above the average, nor will an epidemic originate or continue through a wet year. All epidemics for which accurate statistics are available, have originated in dry years. The most severe epidemics were during four or five consecutive dry years, and in such cases near the beginning or end of such a series of years. Diphtheria, therefore, appears more closely related to a low level of the ground water.

Malaria and Yellow Fever—Malaria and yellow fever are en-

tirely dependent upon the existence of mosquitoes for their transfer to individuals. The presence of mosquitoes is favored by a heavy rainfall and the existence of stagnant or still-water pools. The existence of such pools, however, do not necessarily depend upon a high ground water level, although their frequency is dependent upon the same cause as a high ground-water level. The existence of such pools is a source of danger to the community and should not be permitted. Provision for their drainage has always been followed by a material reduction of the number of mosquitoes and constitutes the only efficient method of dealing with the mosquito evil. The covering of such pools with oil or the attempt to poison the larva of mosquitos is an entirely inadequate method.

Tetanus and Malignant Edema—Tetanus and malignant edema are essentially soil diseases as these organisms are so widely spread in the soil. Both organisms are spore-formers. Both, however, are anaërobes; this fact doubtless explains the reason that infection by either of these organisms is comparatively rare, when we think of the numerous soil-contaminated wounds. There always has been an outbreak of tetanus following Fourth of July injuries. This fact has given rise to the belief that blank cartridges contain the tetanus organism. Negative results have always followed examinations of blank cartridges made for the purpose of establishing the truth of this belief. In all probability the true explanation is to be found in the soil-contaminated hands or clothes and the lacerated character of the wounds of the victim of these infections.

Anthrax—Anthrax is a disease affecting cattle and sheep, and, in a less serious manner, man. Man almost always becomes infected as a result of his contact with infected animals or the hides of animals that have died of anthrax. For this reason the disease is called wool-sorter's disease.

Experiments with the cultures of anthrax show that these bacilli can be carried upwards on the stems of growing plants. It is probable that buried animals do not act as important foci of the infection. Earth worms have been blamed as transporters upwards of buried anthrax organisms, but it is not probable that they are such. Anthrax becomes distributed chiefly in the surface of the ground by the dejecta and secretions of infected animals.

Uncinariasis—Uncinariasis is the most important of all soil diseases and it is essentially a soil disease. The disease is caused by an intestinal parasite called the ankylostoma duodenale. This parasite is a worm ½ inch in length which attaches itself in great numbers to the villa of the upper intestine. It nourishes itself on the blood of its host. The eggs of the parasite are produced in enormous numbers and pass out with the feces. Deposited on moist soil they hatch in about 24 hours and the embryos, after twice shedding their skin, are ready in four to five weeks to infect man. They may enter the human being by the mouth in drinking water or upon green vegetables, etc., or they may attach themselves to the skin where they cause an intense itching and eruption, known as the ground itch, because it so frequently occurs upon the feet. The embryos make their way through the skin into the circulation and by the circulation into the intestines. The eggs will appear in the stools about 7 weeks after the worm has penetrated the skin. The embryos are not infrequently carried to the human beings in food by flies.

The ravages which the disease of unciniariasis has made in the Southern States are most serious. It has been stated that fully 90 per cent of the agricultural classes and the poor in general in the South are infected. The chief symptom of the disease is in an obstinate and not infrequently fatal form of anemia; and while the victim lives, all the evil train of symptoms of secondary anemia will appear.

WATER

Water is of supreme importance to the human race. It not only must be ingested in the alimentary canal in order to replenish the body fluids, but must be depended upon for cleaning purposes. It may truthfully be said that water forms the first necessity of life. Without drink man and animals would die more quickly than without food. A pure water supply is, therefore, of supreme importance.

Classification of Waters—Natural waters may be classified as:

1. Rain and snow.
2. Surface water (rivers, ponds, and basins).

3. Ground water (subsoil water).
4. Artesian water or deep well water.

Rain Water—Rain water always contains considerable of the gases of the atmosphere dissolved within it. These gases dissolve according to their coefficients of absorption. Rain also contains much of the dust of the atmosphere. After each rain the atmosphere is much clearer than before. It may be viewed as an efficient washer of the atmosphere. Much of the rain quickly flows off from the ground into the rivers. Fifty per cent of the annual rainfall in England is lost. The Rhine takes 50 per cent of the rainfall of the country which it drains, the Rhone 42 per cent, and the Seine 67 per cent. Rainwater usually contains [illegible] per cent of its absorbed gases as oxygen.

Surface Water (rivers and lakes)—This water varies much in its source and the character of the soil through which it passes and consequently its composition varies greatly. These waters are subject to many sources of contamination.

Ground Water—The manner in which this water is held and its varying upper level have already been described. The level of the ground water varies considerably; even in level country it does not necessarily correspond with the surface. In hilly country it may, in a rough way, correspond with the contour of the surface.

Ground water dissolves the soluble minerals with which it comes into contact in the soil and in its way through the surface layers. The ground water is in constant motion. This movement is generally in the direction of the nearest large body of water. The rate of this movement has already been discussed. It is controlled by many factors, the penetrability of the soil, the inclination of the strata, and the barometric pressure.

Oxygen in the Water—The amount of oxygen which is dissolved in water is important. At 15° C., 100 volumes of water will dissolve nearly 3 volumes of oxygen. At 20° C., it will dissolve 2.80 volumes of oxygen. Any addition of organic matter to the water greatly reduces its quantity of oxygen. There is a noticeable difference from this cause in the water flowing by or through a town above or below it. The pouring of organic matter into a river will diminish the oxygen sufficiently to kill the fish

The dust falling into the water carries much oxygen with it and forms really a very important agent in the aeration of water. Aeration of water proceeds at great depths and upon this fact depends the ability of fish to live at great depths. In some waters oxygen may be absent at 40 to 50 feet deep. In many wells of depth, oxygen may be absent on account of the reducing effect of salts of iron and manganese which may be present. The presence of oxygen leads to beneficial changes in organic matter which may be present in the water. The absence of oxygen permits of the growth of certain forms of vegetable life which may impart a disagreeable taste or odor to water.

Carbon Dioxid in Water—Carbon dioxid is an important constituent of water. It increases its dissolving properties. It comes primarily from the atmosphere. It is present in large amounts in the ocean and particularly at great depths.

Organic Matter in Water—The amount of organic matter in water varies greatly and its amount and quality bear a very direct relation to health. Organic matter in water may be of animal or vegetable origin. That of animal origin is either sewage or the remains of animal life. That of vegetable origin exists as living and dead organisms and tissues in suspension, soluble and suspended substances given off during vegetable life, and soluble matters extracted by the water from dead vegetable material.

Microscopical Plants in Water—Many numerous species of microscopical plants are present in water. They act beneficently when not present in great numbers by absorbing the products of organic decomposition for their own life. By over-abundant growth they become troublesome. When they die, the products of their decomposition disappear rather slowly and are absorbed by new vegetable growths. When present in excess, these products cause foulness.

The crenothrix Kühniana is a filamentous plant occurring so frequently in waters that it deserves special mention. It grows extensively in ground water and fixes iron as a ferric salt in its gelatinous filaments. The iron so fixed gives the organism a brown stain and renders the water unfit for laundry work. This organism frequently occludes water pipes.

Ammonia in Water—The decomposition of organic matter in water leads to the development of ammonia and this may, therefore,

be taken as an index to the amount of organic matter present in water. The presence of ammonia is, therefore, of prime importance from a sanitary standpoint; because, where much contamination of water by organic matter has taken place, there is always the possibility of pollution by pathogenic bacteria and the presence of food for pathogenic bacteria to multiply upon.

Only under unusual conditions may ammonia exist as the hydrate in water. It usually exists as the chloride or the carbonate. Rain water always adds some ammonia directly to the surface waters. There is more ammonia in the rain of thickly populated districts. In surface waters ammonia is quickly transformed into nitrates. In this form it is rapidly appropriated by plants.

Albuminoid Ammonia—The so-called albuminoid ammonia is ammonia produced in the analysis of water by alkaline potassium permanganate on undecomposed nitrogenous matter. Such organic matter is decomposed with the formation of ammonia. Inasmuch, however, as it may come from animal organic matter and inasmuch as the latter resists natural decomposition longer than the former, the formation of albuminoid ammonia is not of much importance unless we know the nature of the organic matter giving rise to it.

Nitrites and Nitrates—By the nitrifying bacteria the ammonia formed by decomposing organic matter is oxidized to nitrates through the intermediate stage of nitrites. Such oxidization occurs to a much greater extent in the soil water. The nitrite or nitrous acid stage is extremely short. Nitrates are seldom absent and they may be present in as large amounts as 6 or 7 parts per 100,000. While in unpolluted water nitrates are not ordinarily present in as high percentage as one part to 100,000.

Certain anaërobic bacteria known as denitrifying bacteria possess the power in the absence of oxygen of changing the nitrates back to nitrites and ammonia. These species are doubtless numerous, though few forms have been isolated. Because of the absence of oxygen in sewage these species are apt to be present in it. Small amounts of nitrites may also be derived from air due to the contact of the nitrates with metallic or brick surfaces, but they are very seldom present in greater proportions than 1:100,000,000, or over, except as a result of sewage pollution.

Chlorids—Chlorin as sodium chlorid is present in all waters.

It is washed down from the atmosphere, particularly near the coast. Whenever there is distinct increase of the chlorids in water it means pollution. The amount of chlorids varies proportionately with the population of the area drained by the water in question. In specimens of rain water, chlorids are present up to .13 per 100,000. Twenty persons per square mile add on an average of .01 parts per 100,000 to the water of a district in seasons of average flow.

Mineral Matter—The mineral matter dissolved in water depends much upon the character of the ground through which the water flows. Silicate of aluminum is least acted upon and is soluble to the extent of 1:200,000. Silicious rocks in general are attacked only slightly. Limestone, lime, and magnesium carbonates are dissolved with comparative ease. Gypsum is also easily dissolved.

Special waters represented by many natural springs bring much mineral matter to the surface. Iron in traces is present in most waters. One-fourth of a gram per gallon imparts a definite chalybeate taste. Altogether, 50 parts of mineral matter per 100,000 are excessive.

Hardness—Hardness is the capacity of water for dissolving soap. It depends upon the amount of magnesium and calcium in solution. One grain of chalk will form a new combination with the fatty acids of 8 grains of soap before any lather is produced.

Water containing considerable carbon dioxid holds in solution more calcium and magnesium carbonates which may be precipitated by boiling. The water then is not so hard. Such hardness is known as temporary hardness. The chlorid and sulphate of calcium are not affected by boiling. Magnesium carbonate redissolves in cooling water. Permanent hardness, therefore, is due to calcium sulphate and chlorid and to magnesium carbonate; 5 parts of all these salts per 100,000 is regarded as excessive. Calcium sulphate will form a scale in boilers. It is less soluble in hot than in cold water. It forms a very hard scale, while the scale, due to calcium or magnesium carbonate, or temporary hardness is easily removed. A peculiarly hard scale is formed by a combination of parts of lime and magnesium (2.30) in combination with rather large amounts of silica (2.60).

Hardness is not only economically objectionable but it makes vegetables harder in the cooking and more indigestible.

Bacteria in Water—There are some known varieties of bacteria which may be regarded as normal and harmless inhabitants of the water. They are all saprophytic and fulfil useful and nitrifying functions. In addition to saprophytes there may be present pathogenic bacteria or at least bacteria whose natural habitat is man and animals.

Saprophytic Bacteria—Saprophytic bacteria may be present in large quantities in water containing no organic matter. In relatively pure water their multiplication is more rapid than in water containing much organic matter, though in the latter their growth is persistent. They are much more abundant in surface waters. Different varieties are present in unpolluted ground waters. In these, there is an abundance of the liquefying chromogenetic varieties. These characters are sufficiently marked to afford a basis of ascertaining whether ground water, when brought to the surface, has been contaminated or not. Ground water when brought to the surface soon becomes rich in the forms of bacteria usually present in surface water.

There are many causes for variation in the bacterial content of surface water. Sedimentation of matter contained in the surface water carries down the bacteria entangled in such matter. Sunlight and the growth of algæ by consuming the food of the bacteria are important causes of diminution of the bacteria. The bacteria increase in surface water during the winter months and this is probably due to the influx of more nutritive matter.

The Vitality of Pathogenic Bacteria in Natural Waters—Pathogenic bacteria probably do not increase in water whether or not there is an abundance of nutriment. They live for a certain length of time with undiminished virulence and then become altered in this respect and tend to disappear.

Cholera—Cholera bacilli have been found in the Seine water in an active state for seven days' time and in ordinary drinking water for twenty days.

Typhoid—Typhoid bacilli live for various periods according to circumstances. It has been found in very pure water after more than seven weeks. In badly polluted water its life is very short. Sunshine and temperature profoundly affect it. The rays of the sun will kill typhoid bacilli to a depth of 5 feet in 4½ hours, though at double this depth the effect of sunlight is hardly perceptible.

Water Plants

Typhoid organism survives longer in cold than in warm weather, though the reason is probably because of secondary considerations.

Anthrax Spores—Anthrax spores become much diminished in numbers or actually destroyed in a short time in unsterilized water but in sterilized water their virulence remained undiminished for 7 months or more.

Saprophytic Bacteria Specifically Harmful to Pathogenic Organisms—It is to be assumed that the substances excreted by the saprophytic bacteria which are toxic to pathogenic bacteria are not excreted by all saprophytes and that the bacteria specifically inimical to pathogenic bacteria may not be present in all surface waters or ground waters.

Colon Bacilli and its Significance—The presence of the colon bacilli is the most significant guide to sewage pollution. It is true that this organism is sometimes found where its presence cannot be traced to sewage, but, nevertheless, its presence in a majority of 1-cubic-centimeter samples, is a safe guide to pollution of water by sewage.

Water Supplies—Water may be supplied for use by man in the following varieties:

1. Stored Rain Water.
2. Rivers, Lakes and Gathering Basins.
3. Ground Waters, including Wells and Filter Galleries.
4. Springs.

Stored Rain—A house of 40 ft. square having a surface area of 1,600 sq. ft. and a rainfall of 1″ will furnish 997 gallons and at an average rainfall of 43.17 inches a year, it will provide 43,000 gallons a year, or 120 gallons a day.

Automatic devices have been invented for diverting the first fall of water containing the dust and dirt which has collected on the roof. Such cisterns should be protected from contamination by mice or insects and from the sun in order to prevent the growth of algæ.

Surface Water—Surface water is derived from rivers, lakes and artificial lakes. These sources are very liable to contamination. One town, or community, or even a single house frequently furnishes contamination to those situated further down. These waters should be well exposed to sunlight and in the case of artificial lakes the surface layer with its contained organic matter should

be removed at the time the lake is made. When these waters are used for drinking purposes they should be frequently tested and too great care cannot be exercised in preserving them from any contamination by the products of animal life (Fig. 6).

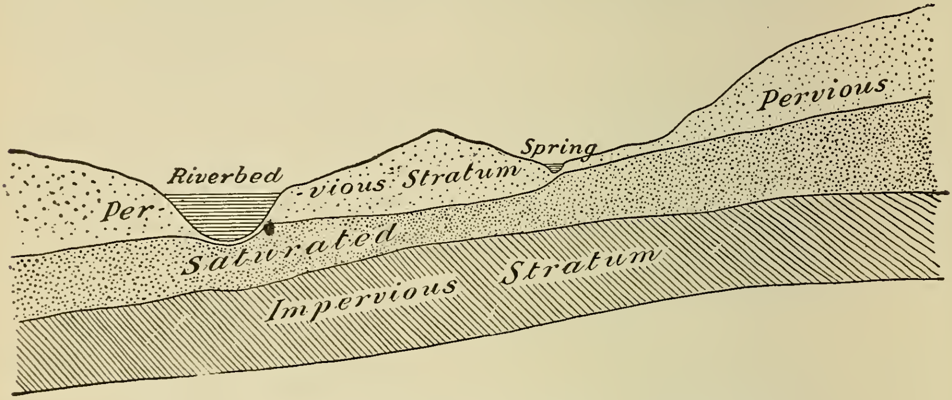


Fig. 6. Outcropping of water table. (Harrington.)

Ground Water—In general this water is purer and preferable to surface water, provided it is not too hard.

Springs—These are the local outcroppings of the underground water table. They are subject to much variation in flow and are by no means immune from contamination by any source of surface

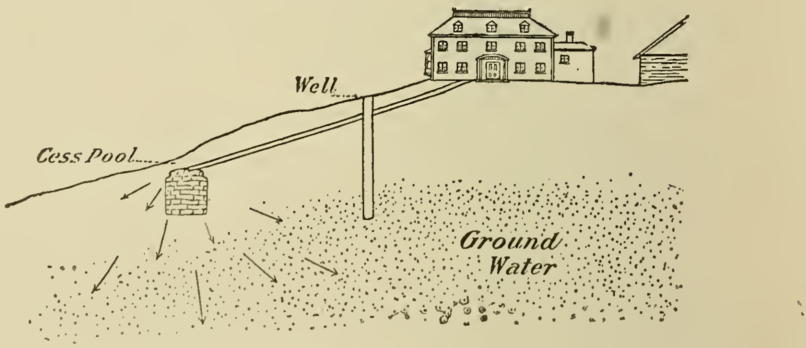


Fig. 7. How a well located on high ground may be polluted by the contents of a cesspool lower down. (Harrington.)

contamination so placed in relation to the underlying strata, that drainage in the direction of the spring is favored.

Wells—Wells may be dug, driven or bored. The only important classification of wells from a sanitary standpoint depends upon the relation of the well to the underlying impervious strata. All wells above this, whatever their depth, are to be regarded as col-

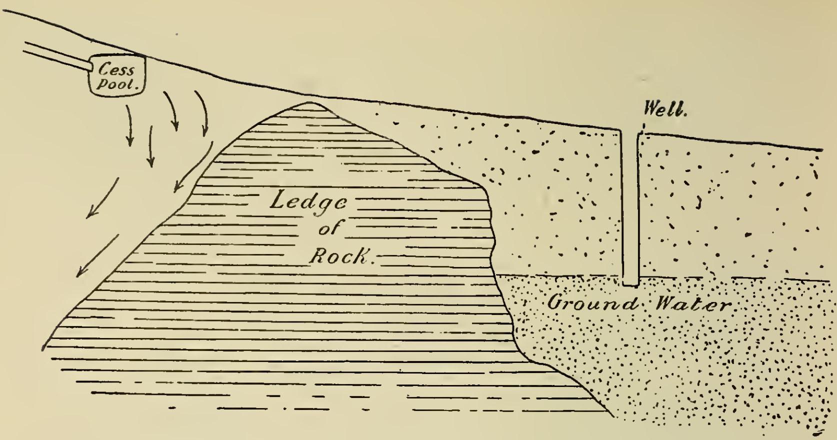


Fig. 8. How a cesspool located on high ground may fail to pollute a well lower down. (Harrington.)

lecting places for ground water and, therefore, for the surface contamination of all the surrounding country so placed in relation to the inclination of the underlying impervious strata, that drain-

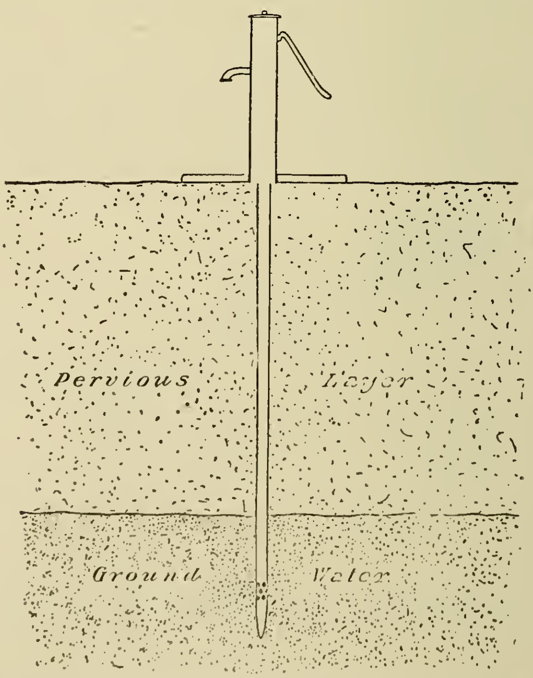


Fig. 9. Norton tube well. (Harrington.)

age toward the well is favored (Figs. 7 and 8). Without control of the surface on the high side of the underlying impervious strata, wells are unsafe. This of course necessitates a knowledge of the

inclination of the underlying impervious strata, which by no means always corresponds to the surface contour.

All wells should be completely closed at the surface in order to prevent the entrance of live things. Their walls should be cemented for a considerable distance below the surface.

Driven Wells are made by driving a pipe 1¼ to 4 inches in diameter into the ground until water is reached. One length of pipe is screwed to another as the pipe is sunk (Fig. 9).

Bored Wells—Bored wells are made practically in the same

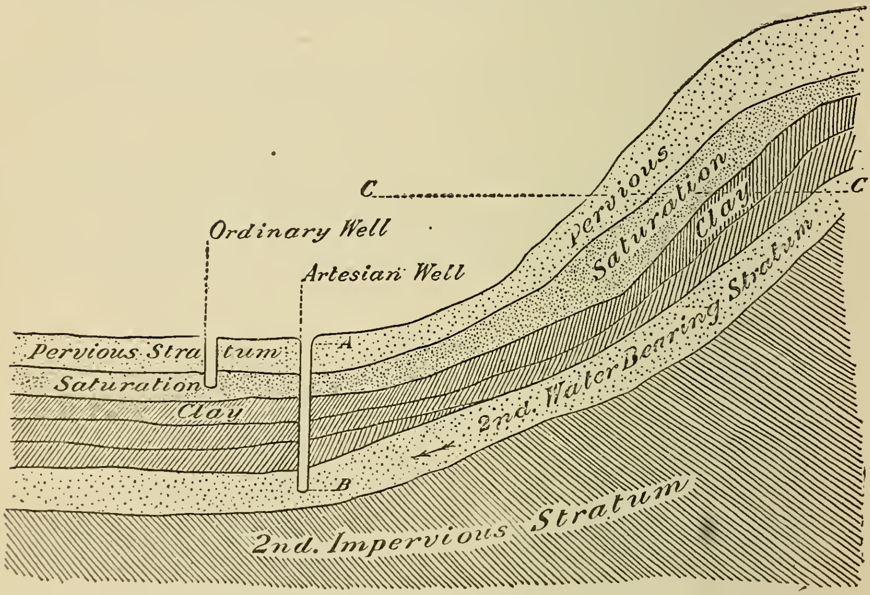


Fig. 10. Geological formation favorable to the obtaining of water by means of artesian wells. (Harrington.)

manner but are much deeper and must be drilled through solid rock and are lined with iron pipe backed with cement as the case may be. Their cost is much greater but they extend through the impervious strata beneath and are many hundred feet in depth (Fig. 10).

These wells possess the advantage of not being contaminated by surface water. Such wells should always be deep, so as not to require forcing, as in this case their bottom forms basin centers toward which water from all directions gravitates in a manner to bring water down from the upper strata and at such a rate as to preclude the purification normally carried on by the saprophytes. The water from these wells usually contains much inorganic matter and is generally warmer than the surface or ground

water on account of the increase of 1° F. for every 55 feet of distance from the surface. Distinctly hot water occasionally met with is unfit for domestic purposes on account of its great solvent power.

One has no means of knowing how far the water from these deep wells has traveled.

Purification of Water—There are several natural methods by which water is purified.

The Soil—The soil has enormous power of purifying water. It accomplishes this purification (1) by mechanical retention, (2) by oxidatic processes of both a chemical and vital nature, and (3) by the saprophytic bacteria within it. All soils, however, do not possess this purifying power to an equal degree. The soils most favorable to the purification of water are sandy or gravelly soils. In these the water is exposed in layers to the air in the interstices between the grains. These grains should neither be too coarse nor too fine.

Importance of Ascertaining the Direction of Flow of Ground Water—Much also depends upon the direction of the flow of the ground water. This direction may be determined by fluorescein. An ounce of this substance will impart a very decided color to an enormous volume of water and can be detected in the direction of the flow sometimes for hundreds of feet.

Efficiency of Natural Purifying Agencies in Surface Water—In surface waters themselves there are a number of purifying agencies. It is in virtue of these forces that the river Isar, two hours after flowing through Munich, becomes as pure chemically as before it entered the city. After 34 miles' flow, the Illinois River is practically free from sewage. The same is true of the Seine and other rivers in England and Germany. There is much difference in the efficiency and number of these purifying agencies of different surface waters.

Oxidation as an Agency for Purifying Surface Water—Oxidation water containing sewage would lose ½ its organic matter when made to run 1 mile through glass tubes with abundant aeration. The nature of these oxidative processes are not thoroughly understood, as agitation alone with air does not produce the expected diminution of contained organic matter.

Dilution as Agency for Purifying Surface Water—Dilution,

while it may diminish the relative proportion of the organic matter, may increase the bacterial content, a factor which is not necessarily an unfavorable one, as the increased varieties may be the saprophytic bacteria, which may still further destroy the organic matter.

Sedimentation as Agency for Purifying Water—Sedimentation is only efficient in very slowly flowing rivers and in lakes. When it occurs, it markedly diminishes the number of bacteria, especially in muddy water.

Bacterial Action as an Agency for Purifying Water—Bacterial action favored by alkalinity may or may not be important, according to conditions. Destruction of pathogenic bacteria by the saprophytic varieties is delayed by dilution and by unpolluted water, which, as above stated, favors their increase for a short time, after which they rapidly decline.

Vegetation as an Agency for the Purifying of Water—The various varieties of vegetable algæ take up all manner of organic substances, including even volatile fatty acids, amino acids, glucose, and urea. Thus they rapidly diminish the food available for the bacteria and may be considered as purifying agents second to none in importance.

Temperature as a Purifying Agent of Water—It has been found that the colon and typhoid bacilli disappear from the natural waters more rapidly in the summer than in the winter time. This is due to the fact that the warm temperature in the summer time is favorable to the growth of algæ and other microscopic plants which do not grow at 0° C.

Artificial Methods of Purification of Surface Water—The artificial methods of purification of surface water are chemical treatment, boiling and distillation, and filtration.

Chemical Treatment—For this purpose chemical substances are employed to cause the formation of insoluble precipitates which settle out and entangle suspended matters, including bacteria, in their descent.

Alum—Alum added to the extent of ¼ grain to a gallon of natural water, which contains a moderate amount of calcium carbonate, is decomposed and forms an insoluble gelatinous hydrate, which combines with the organic matter present, imparting a color and settling out as a flocculent precipitate. As an accessory

change during the decomposition of the alum, sulphuric acid is set free which unites with the lime or other bases present. The calcium sulphate thus formed is insoluble and also settles out, thus further purifying the water. When calcium carbonate is deficient, limewater may be added and the same result obtained. If it is desired to avoid the formation of sulphuric acid, the addition of freshly precipitated aluminæ serves equally well.

If carbon dioxid is present in the water, the addition of limewater alone will cause an efficient precipitate by uniting with the carbon dioxid and forming calcium carbonate. Moreover, the removal of the carbon dioxid causes a precipitation of the natural calcium carbonate which was held in solution by the carbon dioxid.

Potassium Permanganate—Potassium permanganate has been used. Enough should be added to give a slight color for 24 hours, but little can be said in its favor.

Hydrochlorites—Hydrochlorites are also oxidizing agents and act much like potassium permanganate. Neither of them retain their identity for any length of time in water. When a bleach (a double salt of calcium hypochlorite and calcium chlorid) is used in combination with alum as an adjunct to mechanical filtration, a more satisfactory removal of the bacteria and a less expensive one is obtained than when sulphate of alum is used alone. In such a process, disinfection occurs in the coagulation basin before the water reaches the filter and the subsequent filtration adds another factor of safety. Experiments show that 0.9 grains of sulphate of alumina and 0.7 grains of soda per gallon, in combination with bleaching powder, are equivalent to 0.11 parts of available chlorine per 100,000, and give the best results.

The use of hypochlorites cannot be considered as a substitute for filtration of water, but as an adjunct it has a distinct field of usefulness. It makes possible, moreover, higher rates of filtration and it thus becomes an economy. Its use results substantially in the destruction of objectionable bacteria, particularly those of intestinal origin.

There is a total absence of poisonous features in the end products. The use of hypochlorites permits of high rates of filtration when the bacterial content is high. The speed of the reaction is immediate and the cost is nominal. It does not destroy spore-formers nor does it remove turbidity or appreciable amounts of

color, dissolved vegetable stains or organic matter. It does not soften water but rather slightly increases its hardness. There are, moreover, difficulties of applying the method, except with the greatest care, to waters which contain substantial quantities of reducing agents, or compounds capable of oxidation such as nitrates and unoxidized iron. If, however, used in connection with filtration, none of these objections are very serious.

Bromin, Ozone, Bisulphates, and Copper—The use of bromin, ozone, sodium bisulphate, and copper sulphates are to be mentioned only to be condemned. Copper sulphate, 1 part to 4 to 5 millions, destroys with the bacteria and the algæ which are valuable agents working toward the same end as the disinfectants.

Ultraviolet Light—The ultraviolet light has been suggested. Applied efficiently it produces an extensive destruction of bacteria and practically a complete sterilization of clear water; but as a practical method of disinfection of public water supplies, it is hardly feasible.

Boiling—For domestic use, boiling the water is a convenient and reliable means of rendering it pure. The flat taste may again be restored by aeration. This can be simply done by pouring it from one vessel to another. It should always be practised when suspicious water must be depended upon.

Filtration—The only domestic filter of any use is the Chamberland Pasteur filter (Fig. 11) and the Berkefeld filter. The Pasteur filter is made of well-baked kaolin of the proper degree of porosity and hardness. The Berkefeld filters are more porous. They are now made of a special blend of clays used in the manufacture of the finest porcelain.

Bacteria will grow through these filters. It has been repeatedly proved that normal water and water artificially infected will yield on the first day a perfectly sterile filtrate and on the second or third day a very small number of bacteria will be present in the filtrate but these are the ordinary water bacteria. The pathogenic varieties appear considerably later. The shortest time in which the typhoid bacillus has passed has been 4 days. In order to keep these filters safe it is necessary to scrub them and boil them twice a week.

Filtration of the public water supply of towns and cities on a large scale, by passing the water through sand and gravel arranged

in layers composed of pebbles and grains of proper size, has proved to be an important and efficient method of purifying water. They

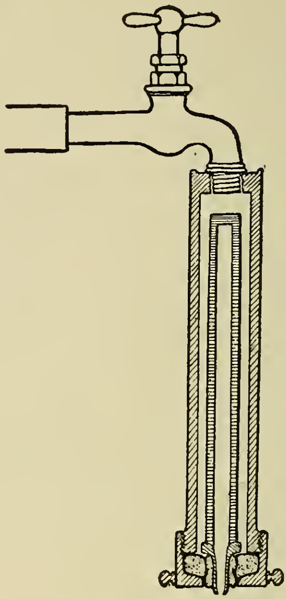


Fig. 11. Chamberland-Pasteur filter. (Harrington.)

consist of immense tanks of concrete (Fig. 12). Upon the paved bottom is laid a system of perforated or disjointed pipes. Above these are successive layers of coarse gravel, fine gravel, coarse sand

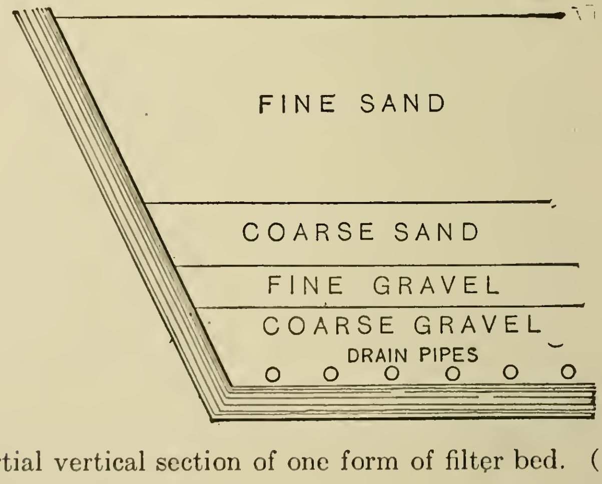


Fig. 12. Partial vertical section of one form of filter bed. (Harrington.)

and fine sand, the latter being 3 to 5 feet in depth. The fine sand is sharp-grained in character, though the sand of the seashore may be used. It should not contain clay. The size of the sand particles

should be 1/5 to 1 mm. in diameter and possess the volume of a grain.

Before the water is allowed to flow upon the filter, if it comes from a turbid river, it is advisable to let it stand several days in a settling bed or basin. The suspended matter is thus loosened in amount and the organic content diminished or destroyed by bacterial action. The bacteria themselves finally become diminished in virtue of being carried down by the material settling out and by the death of the less resistant varieties.

The water is delivered continuously at the surface of the filter by automatically regulated devices. The first water coming through the filter is not much better than the affluent, but there soon forms around each grain of sand at the surface a gelatinous growth of algæ, which entangles the suspended matter. This superficial layer removes mechanically the solid material and bacteria in the water. By means of the water-bacteria which accumulate in the filter, the organic matter and finally the bacteria themselves, at least the less resistant forms, are destroyed.

All organic matter is not acted upon to the same extent during filtration. Some is decomposed very rapidly and mineralized, while other matter is acted upon so slowly that complete removal during passage through the filter is impossible. This latter class of organic matter includes the brown coloring matter of vegetable origin, so common in surface water. It forms a very stable compound and nitrifies slowly. By the alum process of coagulation, it is coagulated and quickly removed.

The efficiency of the filter as a whole is demonstrated by the fact that the sluice layer at the surface may be stopped off without changing the bacterial count of the effluent. Unquestionably the most of the filtration is done in the upper layers of the filter. The active agents in bringing about the death of the bacteria contained in the effluent and in accomplishing the destruction and mineralization of the organic matter, belong to the same class of nitrifying organisms which are commonly at work in the soil.

It is important that the filtration should be uniform over the whole filter. It has been proved by the Board of Health of the State of Massachusetts, that 2,000,000 gallons can be filtered through 1 acre of filter bed per day with the removal of substantially all the bacteria present.

The downward movement should not exceed 100 mm. per hour. The filtrate of each section should be examined daily while the bed is at work and a filtrate containing more than 100 bacteria to the cubic centimeter should be rejected.

When the filter begins to filter slowly it is not safe to increase the pressure. Such a procedure has been accompanied with an outcrop of typhoid.

When the filter shows signs of clogging, an inch or two may be scraped off from the top of the filter and the filtration proceeded with anew. Successive cleanings may take place without replacing the sand until the depth of the filtering material is reduced to 15 inches. The scraped-off sand may be washed in a special machine until it shows no turbidity and stored for later use in the filter. Sterilizing the sand is harmful because it kills the saprophytes.

In winter the filter beds should be covered in order to prevent freezing, which is responsible for imperfect and uneven filtering. The removal of ice is expensive and injures the surface layer of the filter. It is also an advantage to cover the filter beds in summer, as by so doing the growth of algæ is prevented. This reduces the necessity of so frequently cleaning the filter.

It is an advantage to give the filter a rest for a part of each day, as by so doing the interstices of the filter become filled with air, which is an important factor in the completeness with which the process of nitrification will be accomplished.

Intermittent filtration makes necessary, of course, an increase in the area of filter bed.

By mechanical filtration, a form of filtration used in a number of places in the United States, is meant the passage of water under pressure, at a comparatively fast rate of speed through coarse sand or crushed quartz contained in an iron or wooden cylinder.

Alum is used as a coagulant and thus an artificial film is produced. It is called mechanical only because of the power needed to force the water through, and the raking and shaking in the process of cleaning, which must be done at comparatively short intervals. This method of filtration replaces entirely the top slimy layers.

Mechanical filtration is particularly valuable for the highly

colored and turbid waters of the West. With careful manipulation it may remove 99 per cent of the bacteria.

The Removal of Hardness—Temporary hardness may be removed by boiling, which is too costly a method for use on public waters, or by the use of limewater. Limewater does not affect the sulphates and chlorids. For the removal of permanent hardness, caustic soda or sodium carbonate may be used. The removal, however, of the temporary hardness is as a rule quite sufficient and involves a considerable saving of expense and labor in washing. In Southampton, England, 2,000,000 gallons of water are treated daily with limewater at an almost insignificant cost.

Contamination of Water by Poisonous Metals—Water takes up an appreciable quantity of iron from iron pipes and zinc from galvanized iron pipes and lead from lead pipes. Probably chemically pure water would not do so, but no actual waters are free from carbon dioxid and oxygen, which increase its solvent action on metals.

Where lead pipes have been in use, numerous instances are on record of chronic and even fatal cases of lead poisoning from this cause. At Summerfield, where a number of cases occurred in 1888, 6 milligrams per liter were found.

Sulphuric acid is not infrequently in water and the so-called peaty acids. Acids developed in water coming from peat deposits possess the power of dissolving lead. Peaty water comparatively poor in carbon dioxid can take up 300 parts of lead per 100,000 over night.

Ammonium compounds and nitrates in water exposed to the air have a solvent action on lead. A certain protection is afforded to older lead pipes by certain waters on account of the formation of an insoluble coating formed from the chlorids, carbonates and silicates. Sodium and calcium carbonate are very efficient in this particular; bicarbonate of sodium, so generally present in soft waters, is less so. Calcium carbonate is efficient whether carbon dioxid is present or not. Four grains to the gallon are quite sufficient to afford protection.

The use of galvanized iron pipes is no protection against the corroding effect of the water on the pipes and the solution of the zinc of the coating of the pipes. The lining is easily corroded, if the water contains oxygen, carbon dioxid and ammonia or nitrates,

so that the water is actually made milky by the oxid and carbonate in suspension as a result of this action. The zinc compounds are not especially toxic but they are capable of causing constipation. Occasionally gastro-intestinal pain, diarrhea, and consequent anemia, and emaciation and a spurious kind of dysentery, have resulted where considerable amounts of zinc have been dissolved. As much as 5 grains per gallon have been found in some natural waters (Tutendorf). No unpleasant effects were noticed by those who used the waters.

WATER AND DISEASE

There are three main water diseases, (1) Typhoid, (2) Cholera, and (3) Dysentery.

The Danger of Water Contamination by the Bacillus Typhosus—The strongest proof of the relation of the water supply to typhoid fever is the immediate drop in the mortality from this disease whenever a city in which the disease had been frequent has adopted purified water. Lawrence, Mass., prior to 1893 used unfiltered water from the Merrimac River, which was polluted by several towns above Lawrence. The following figures give the death-rate per 10,000 of the population before and after the installation of a public filter in 1893:

Preceding the use of Filtered Water—

1889	12.7
1890	13.4
1891	11.9
1892	10.5
1893	8.0

After the use of Filtered Water—

1894	4.7
1895	3.1
1896	1.9
1897	1.6

The city of Hamburg adopted filtration in 1893 after a most devastating epidemic of cholera. The typhoid death-rate had

always been high. From 1890-93 the death-rate was 2.6 per 10,000. During the year 1894-95 it fell to 0.75.

In Philadelphia during the first six months of 1899, there were 7,035 cases of typhoid with 800 deaths in a population of over 1,000,000. Between January 1st and April 11th, 1904, in a population of 1,300,000 there occurred nearly 2,500 cases and of these no fewer than 389 were reported in a single week. In that part of the city, however, in which the new supply of filtered water was used there was an immediate drop in the typhoid rate.

Methods of Contamination of Water by Typhoid Bacillus—Typhoid contamination of water may be direct when sewage containing the bacilli flows directly into the water or indirectly when the bacilli in feces and urine are washed by the rain into the water courses. The harmful possibilities of the pollution of water by the discharges from typhoid individuals depend upon the period during which the feces and urine of infected individuals contain bacilli, and the length of life of the bacilli after discharge from these individuals. The bacilli as a rule exist in the feces of sick individuals only during the early stages of the disease and up to the 20th day, though the intestinal mucous membrane may in some individuals give them up for very long periods. The urine has been found to contain many millions of the bacilli in each cubic centimeter and they may be contained in the urine for many weeks even after convalescence is well established. An apparently well person may be capable of giving off bacilli for long periods.

In the water courses the tenure of life of the typhoid bacillus is not a long one and due to the dilution of the water the bacilli may never reach many individuals drinking the water.

Because of these considerations, the highest death-rate from typhoid fever is not in the large cities but in towns which have no public water supplies. In other words special and small water supplies, contaminated in a manner to produce a special concentration of the bacilli, are far more dangerous. Nevertheless, the public water supplies are a very real source of danger and the diminution of the death-rate from typhoid fever by special provisions for the purity of the water supplies fully justifies such precautions.

The Danger from the Water Infected by Cholera Bacilli—

Cholera, even more than typhoid, is a water-borne disease. Where no special measures are taken to guard against the use of impure water, its ravages are very horrifying. In India the disease is endemic and from there it makes periodic excursions into the rest of the world.

In one of these excursions, in 1892, from the valley of the Ganges through Persia, the disease claimed 20,000 victims in Teheran alone, and in its course through Russia killed 215,157

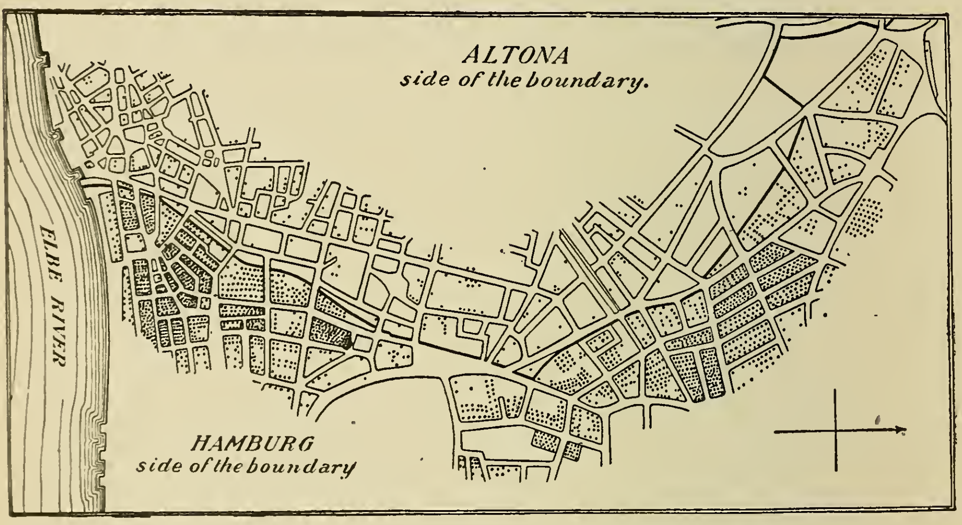


Fig. 13. Portion of the boundary line between Hamburg and Altona. The dots indicate cases of cholera. (Harrington.)

more persons. Regarding the danger from polluted water supply no more speaking example could be furnished than the experience of Wandsbeck, Altona and Hamburg. Wandsbeck was supplied with filtered water from a lake but little subject to pollution. Altona was supplied by filtered water from the Elbe drawing the water below Hamburg and, therefore, from water contaminated by the sewage of Hamburg (Fig. 13). Hamburg drew its water from the Elbe, but inasmuch as it was situated above Altona on the river it did not filter its water. During the epidemic above referred to, in the summer of 1892 (between August 17 and October 23), Hamburg, with a population of 640,000, had nearly 17,000 cases of cholera, of which more than 50 per cent died. Altona, ¼ the size of Hamburg, had only 500 cases, 400 of which came over from Hamburg. In the first week of December and again at intervals

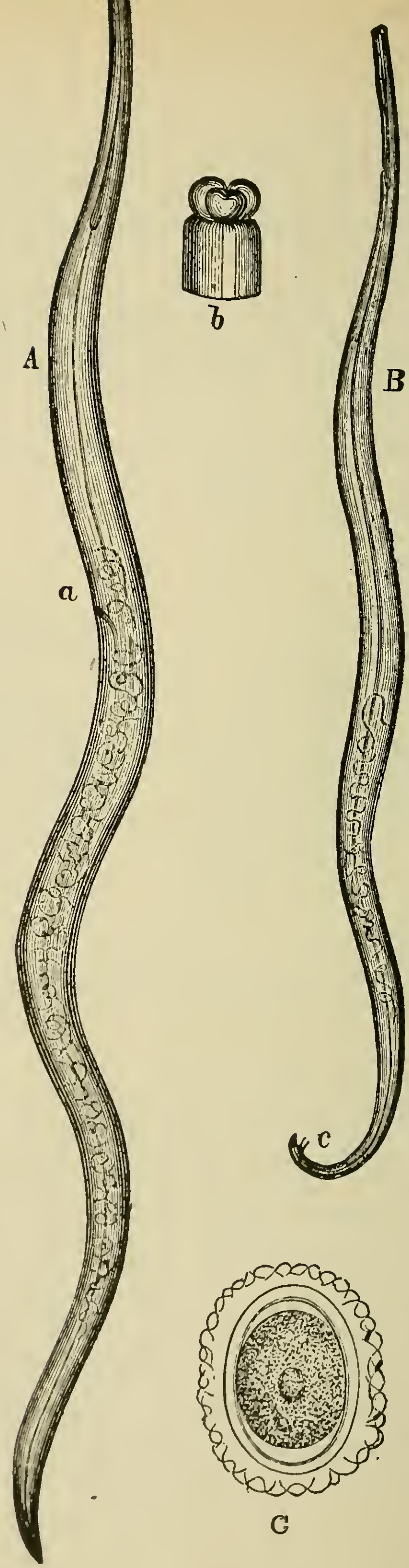


Fig. 14. Ascaris lumbricoides: A, female; B, male; C, egg. At a, the female genital opening; b, the enlarged cephalic extremity, with its three lips; c, the male spicules. (Simon.)

in January there was an increase in the number of cases in Altona. Investigation showed that at these times the filter was not working perfectly because of freezing during the cold weather.

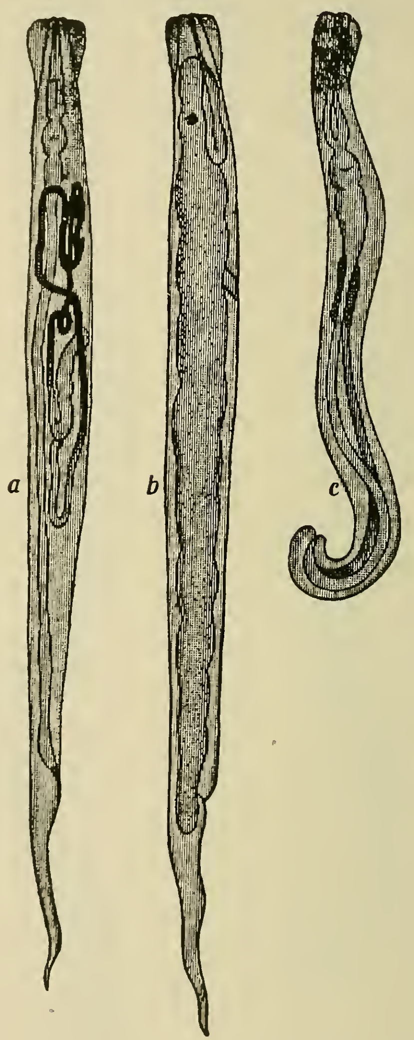


Fig. 15. Oxyuris vermicularis: a, sexually mature female; b, female filled with eggs; c, male. Magnified, 10. (Simon.)

The home of cholera is India and will unquestionably continue to be so long as the filthy habits in attending to the calls of nature and disposing of the dead continue. The evils are aggravated by the crowding at the religious festivals of the country.

Parasitic Diseases Conveyed by Water—Besides these bacterial diseases, water is responsible for a number of diseases which are due to vermiform parasites.

Round Worms, Ascaris Lumbricoides (Fig. 14)—Round worms, *ascaris lumbricoides,* are probably spread by drinking water. The female yields numerous eggs which pass out with the feces and may require another host for their full development.

Pin Worms, Oxyuris Vermicularis—Pin worms also are probably spread by drinking water. They inhabit the cecum and upper colon and yield an enormous number of eggs (Figs. 15 and 16).

Guinea Worms, Dracunculus Medinensis—Guinea worms are believed to invade the body through the skin of bathers or through the stomach when ingested in drinking water. The gastric route

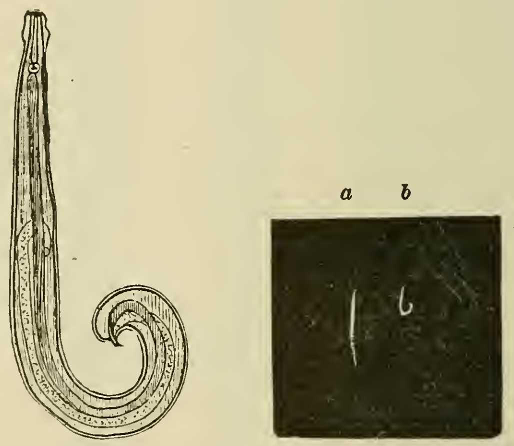


Fig. 16. Oxyuris vermicularis: a, male; b, female; natural size. Magnified, 2. (Simon.)

has been proved. In the stomach the embryos become rapidly mature and the impregnated female proceeds to the subcutaneous tissues of all parts of the body through which she finally breaks and escapes. The liberated embryos finding themselves in fresh water enter the bodies of the common fresh water flea which acts as the intermediate host. These worms are of unbelievable length when they are in the subcutaneous tissues, often 25 inches.

Thread or Whip Worm, Trichocephalus Dispar—The thread or whip worm is an intestinal worm about 2 inches in length. The front part of the body is hair-like in slimness. It enters the body probably in drinking water.

Filaria Sanguinis-hominis—This worm enters the body from drinking water. The adult enters the thoracic duct or large lymphatic trunk and produces countless embryos which invade the

blood stream during sleeping hours (Fig. 17). Mosquitoes then suck the blood of the afflicted individual and act as intermediate hosts. By the mosquitoes the embryos are transferred to drinking water.

Bilharzia Hematobia—This worm inhabits the pelvis of the kidney and causes a peculiar hematuria and often stone. It is

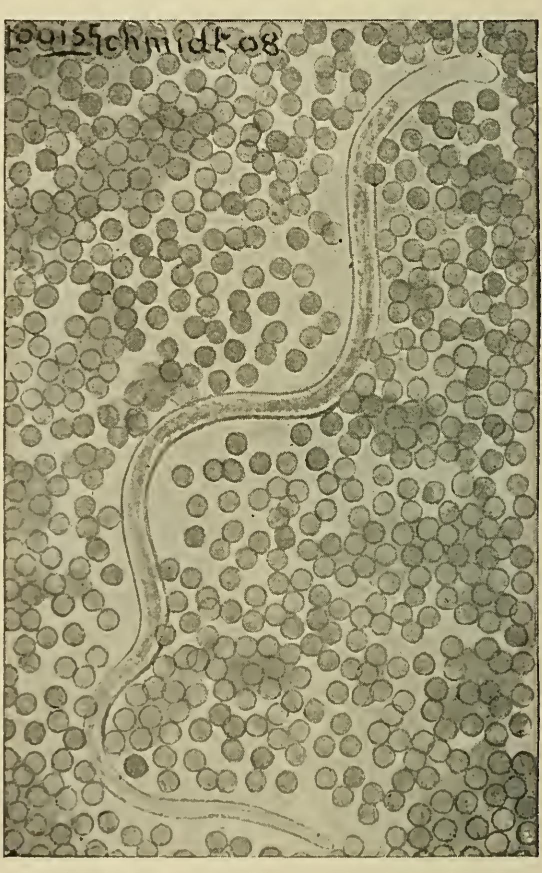


Fig. 17. Microfilaria nocturna. (Wilson.)

believed to enter polluted water from the urine of infected individuals.

Ankylostomum Duodenale (Figs. 18, 19, and 20)—This worm has already been mentioned. It is probable that the chief source of infection is the soil.

Strongyloides Intestinalis—The parasite of an endemic diarrhea of China is strongyloides intestinalis. The embryos occur in the stools and are transferred by drinking water.

The Danger of Bacterial Infection from Ice—Ice is seldom a

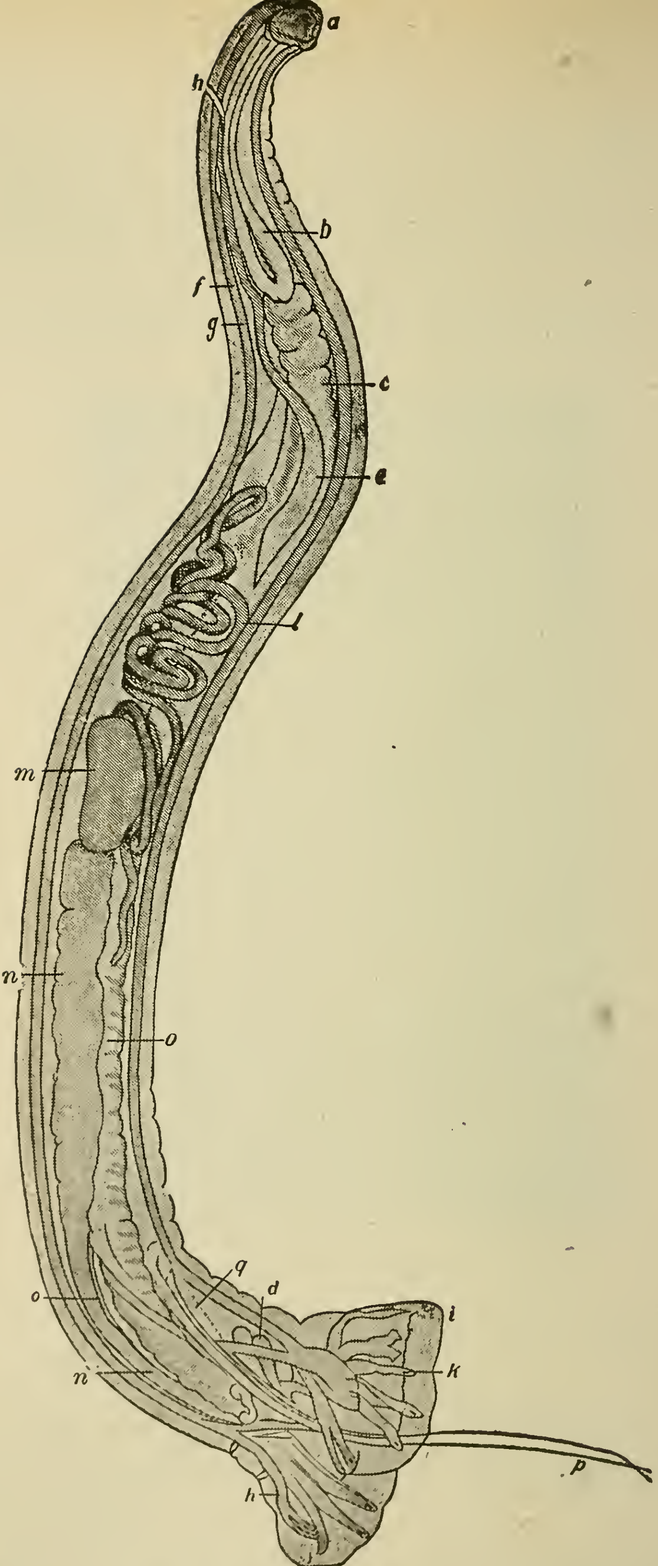


Fig. 18. Male ankylostoma duodenale: a, head; b, esophagus; c, gut; d, anal glands; e, cervical glands; f, skin; g, muscular layer; h, excretory pore; i, trilobed bursa; l, seminal duct; m, vesicula seminalis; n, ductus ejaculatorius; o, its groove; p, penis; q, penile sheath. Magnified, 20. (Simon.)

source of danger of bacterial diseases. Most of the bacteria are eliminated by the process of freezing, as has been proved, experimentally using the colon bacillus in polluted water as a test. Occasionally in exceptional circumstances, particularly where rapid freezing has taken place and actual sediment is included in the ice, the ice may be a cause of the transfer of typhoid and of

Fig. 19. Ankylostoma duodenale, male and female. Natural size. (Simon.)

other water bacterial disease. In this connection it must be remembered that bacteria are not killed by the cold.

Quite apart from diseases due to bacteria in water are the disorders associated with a high content of mineral matter in the water. It has been noticed that a change to hard water from

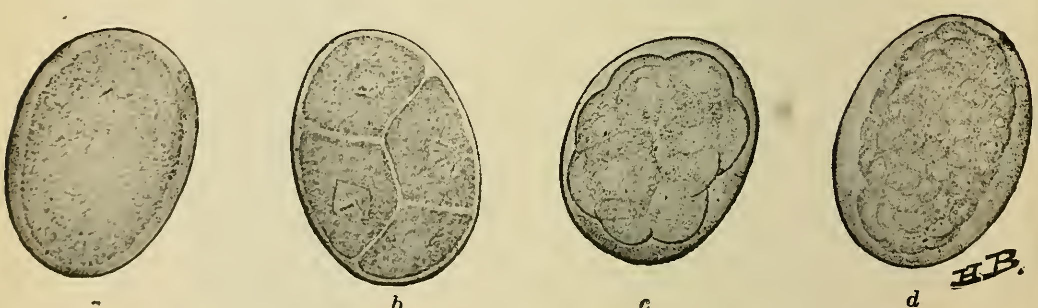


Fig. 20. Eggs of uncinaria duodenalis. a, unsegmented; b, with four segments and showing nuclear spindles; c and d, later stages of segmentation. X 400. (Wilson.)

soft water may cause constipation and a change back again unusual looseness of the bowels. From 10 to 15 parts of inorganic salts per 100,000 is to be regarded as undesirable. The use of hard water probably has no connection with stones in the bladder. The disease most commonly associated with water, apart from its bacterial content, is goitre. There can be no doubt but that in certain districts, where goitre is frequent, the cause of the hypertrophy of the thyroid gland is to be found in a filterable agent

passing into the water, either as an infusion from some organic constituent, or as the result of bacterial action upon the organic sediment in the water.

HABITATIONS

The houses in which human beings live and the buildings which they frequent have much to do with health.

Sunlight—The more sunlight which a house can receive, the more hygienic will be the interior of the house. This means that the windows must be large and numerous and the house, whenever possible, so placed that sunlight will stream into it during most of the day. If the front faces the South, the opposite side of the house will face the North and receive no sun. Consequently, it is better that the corners of the house should face the points of the compass; when such is the case, all sides of the house will receive some sunlight during the day.

Construction of Houses—As regards the construction of the house, stone or concrete unquestionably furnish the warmest house in the winter and the coolest in the summer. Concrete is better than stone, as it does not retain dampness. Clapboards have many advantages in permitting good ventilation through the walls, though they are wasteful of the heat.

No portion of a house is of greater importance than the cellar. Its floor and walls must be impervious to gases and water. This condition is generally best accomplished by a generous layer of cement.

Roofs must be light and slate or asbestos shingles or tiles are much to be preferred to shingles. Tin is poor, as it is hot and apt to rust. Gravel and tar are very good for flat roofs. The gravel protects the tar against the action of the sun.

An important part of the house is the kitchen and its immediate surroundings. All that pertains to the kitchen must be clean No filth or waste should be permitted to remain in any receptacles in its vicinity. The daily waste should be kept covered. There should be no necessity for a "spring cleaning" for the perfectly clean house knows no cleaning seasons. As regards methods of cleaning the rest of the house, nothing equals an efficient suction

cleaner. No dust is made by these cleaners; that is, the dirt in the room is not simply dusted off from one place and allowed to fall on another, but is taken from the place where it may happen to be, directly into the cleaner, from which it may be taken outside without scattering it again through the house.

Schools—The windows of schools should be large and numerous, and in their total sectional area should equal one-tenth to one-fourth of the total floor space. The desks should be so placed that the light comes from the left of the pupils, in order that their bodies and pens will not cast shadows. They should have a slant of 10 to 20 degrees. The chairs should be comfortable, with straight backs and seats, which support the bodies in the middle of the thighs. The cloakrooms should be spacious and well ventilated and allowing plenty of room between each child's clothing.

Water closets and urinals demand unusual care, inasmuch as children are prone to carelessness in these rooms. Blackboards should have a dull black finish and never placed between windows. Copying from the blackboards should not be encouraged on account of the constant strain upon the eyes incidental to frequent change of focus.

Ventilation—Each individual requires 3,000 cubic feet of air hourly. This will not furnish the individual with the ideal conditions of out-doors but will keep the percentage of carbon dioxid down to .6 to 1 volume in 10,000, and this is good ventilation. Artificial lighting greatly increases the consumption of oxygen and the impurities in the air in the room. About 3 to 5 cubic feet of gas are burned from an ordinary burner per hour and require for their proper dilution 1,500 to 10,000 cubic feet of fresh air.

The impurities added to the air by illuminating gas are carbon monoxid, the sulphur acids, the nitrogen acids, marsh gas, ammonia compounds, and unconsumed carbon. Calculated on the basis of quantity of light produced, candles and kerosene lamps produce 40 to 160 times as much impurities as illuminating gas.

Every building must, therefore, possess some means of constantly supplying fresh air to its interior.

Natural Forces of Ventilation—There are many natural forces in ventilation.

Diffusion—Each gas possesses its own coefficient of diffusion

proportionate in general to its molecular weight and of 2 cases the rate of diffusion into each other is proportional to the square roots of their densities.

Diffusion, as a force for eliminating from a house objectionable gases and providing in their place fresh air, is a totally inadequate means of ventilation.

Gravitation—Gravitation is a stronger force in ventilation than diffusion. It is greatly assisted by temperature. In any inhabited room there are always sources of heat which create convection currents. The sources of heat are the individuals inhabiting the room and the artificial heating and lighting devices.

Winds—Currents of air either from gravity currents on the inside or the current of winds on the outside will pass through most of the materials composing the walls of a house, including, certainly, brick and stone. Wall paper, paint, and tight joints all oppose these natural forces of ventilation, but notwithstanding the drawback of these conditions, from which we cannot always be independent, much may be accomplished by supplying intelligently placed inlets and outlets. In warm weather large and numerous windows which may be left open will permit of diffusion, and allow the natural currents in the air to supply a sufficient quantity of fresh air. During the winter, however, every quantity of fresh air brought from the exterior must be heated and the greater the ventilation the greater the amount of heat which must be produced inside the house. The aim in ventilation, therefore, should be to adjust the renewal of air so that an unnecessary waste of the heat produced within the house should not occur. It is better, therefore, to provide a house with fairly tight walls and to provide for a definite plan of ventilation within the house. Such a plan includes provision for inlets and outlets.

Inlets and Outlets for Ventilation—A simple form of outlet is the cowl. The ordinary type of rotary cowl constitutes obstruction to the egress of air rather than otherwise. The aspirating cowl, on the other hand, opens horizontally and is always held by a vane above it in the direction towards which the wind is blowing. It constitutes an efficient aspirating device. Cowls may be placed over chimneys or ventilating flues (Figs. 21, 22 and 23).

Windows with boards placed beneath them constitute simple inlets and outlets. The cold air from the inside strikes the lower

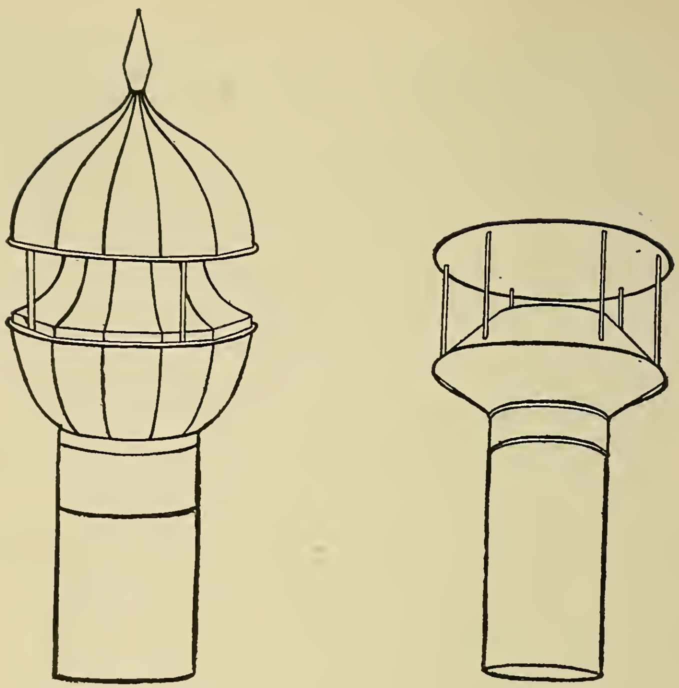


Fig. 21. Common forms of stationary ventilating cowls. (Harrington.)

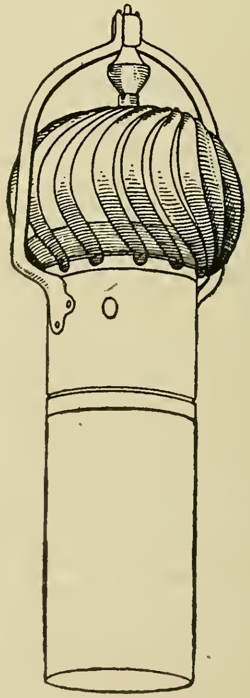


Fig. 22. Rotary cowl. (Harrington.)

sash and is thrown upward between the lower and upper sash into the room. Due to its original force of entrance it rises toward the ceiling. From here it falls toward the floor. In its passage in this manner through the room, it creates currents which assist in thoroughly mixing the air in the room. In the usual house the lowering of the upper sash of certain windows upon the windward side of the house and of others upon the side upon which the wind creates aspiration currents, will provide for the

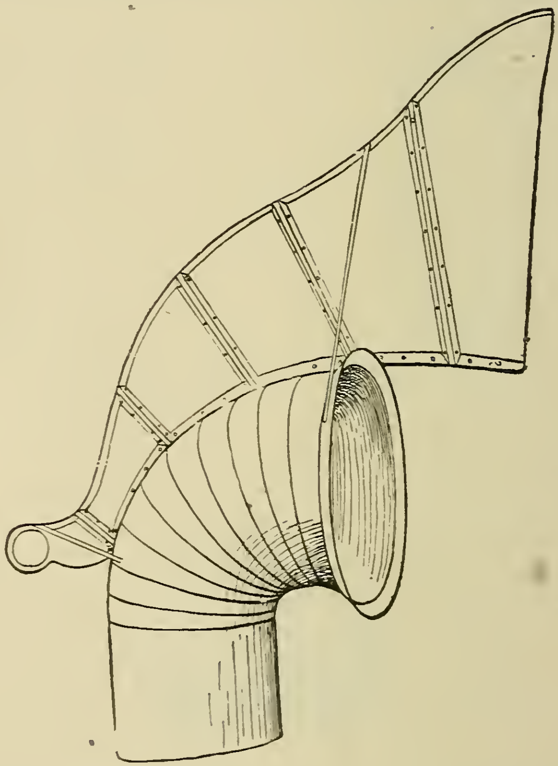


Fig. 23. Aspirating cowl with vane. (Harrington.)

entrance of fresh air, which will become warmed in its passage towards the floor and the removal of the warmed air which has passed upwards toward the ceiling. In buildings occupied during only a small part of the day, as some schools and churches, special means of ventilation may be dispensed with and dependence placed upon a thorough airing after use.

Special Means of Ventilation—When it is desired to provide for special means of ventilation, it may be done sufficiently only by provision for properly placed inlets and outlets and of suitable means of heating. The underlying principle is that there should

be a thorough blending of the incoming air. The inlets and outlets should not be so placed as to favor a direct current between them. In general the inlets should be placed on the inside wall and as near as possible to the center of the horizontal length of the room. If the incoming air, entering through these inlets, is heated, the inlets may be placed high or low; but if the incoming air is not heated, the inlets should be at least above the heads of the occupants.

Part of the air which has entered and risen to the ceiling comes

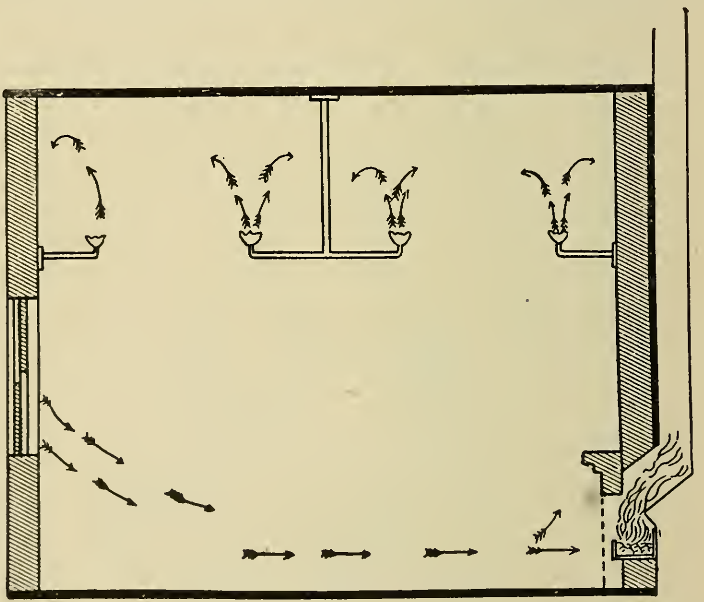


Fig. 24. Direction of air-currents in room lighted by gas and heated by open grate. (Egbert.)

into contact with the windows and cooler outside wall of the room and this portion then sinks toward the floor and becomes sucked toward the inner wall by the aspiration currents set up by the rising of the entering air and by the aspiration through the outlets which should also be on the inside wall. If the incoming air is heated, the outlets may be high or low, but if the incoming air is not heated, the outlets should be high, as in this case the colder air entering sinks to the floor and then becoming heated, rises, carrying with it the other impurities in the room, and if it now meets the outlets placed high it will be removed at a proper time.

The efficiency of the inlets and outlets is greatly increased by the creation in them of currents of air, depending, in the case

of inlets, upon mechanical propulsion, and in the case of outlets, upon heating the air in the flue beyond the connection with the room (Fig. 24). Only one of these methods is needed, as if air is

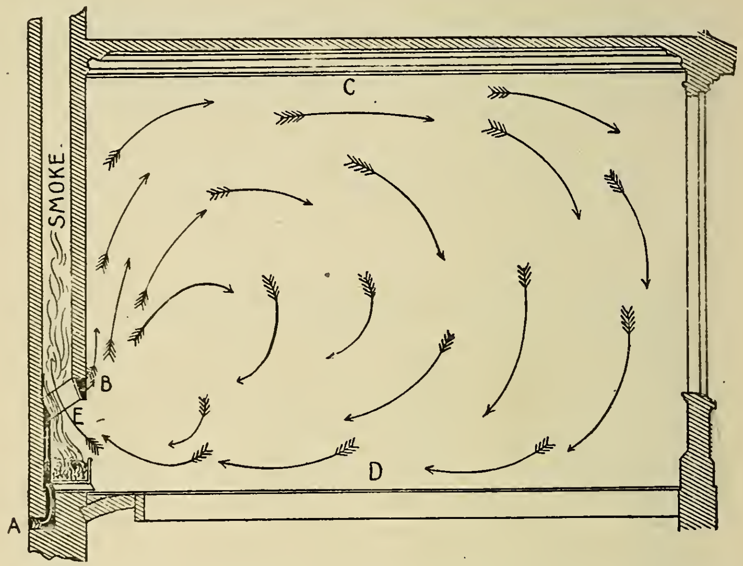


Fig. 25. Direction of air-currents in room heated by a ventilating grate. (Egbert.)

forced into a building by mechanical propulsion it must necessarily displace the used air already within the building. And, if air is aspirated out of the rooms of a building by heated flues, the aspira-

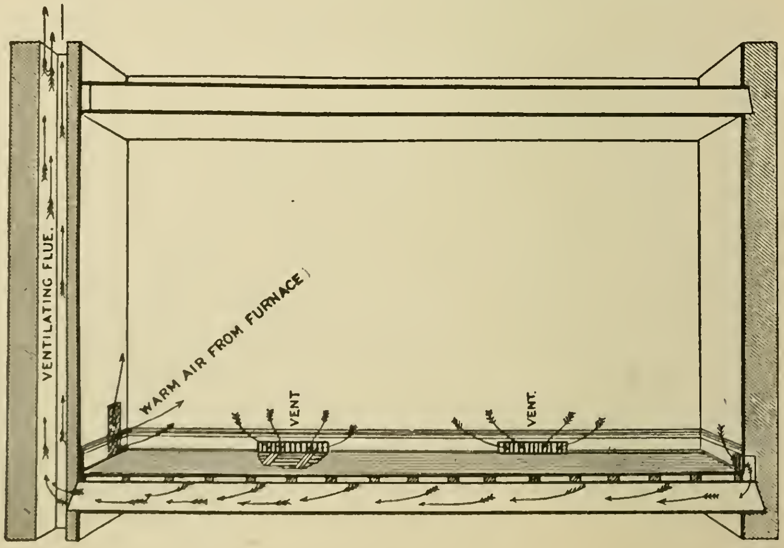


Fig. 26. Illustrating the Smead system of ventilation. (Egbert.)

tion must create a lower pressure, which will determine the drift of fresh outside air to take the place of the air removed (Figs. 25 and 26).

The Quantity of Fresh Air Needed per Individual—In calculating the quantity of fresh air which it is necessary to supply, provision must be made against the occurrence of perceptible draughts. It has been demonstrated that 2,500 cubic feet can be passed without draughts through a space 8 x 8 x 6.5 per hour. It will thus be removed six times. The minimum space allotted to each individual, therefore, should be 500 cubic feet. In larger spaces the changes can be more frequently made without creating draughts. Thus, in a hall 40 x 20 x 15, 40 persons may get 3,000 cubic feet per hour with an allowance of 300 cubic feet to each individual without a draught.

In large halls, churches, etc., 300 cubic feet per hour for each individual is not practical nor necessary, insomuch as such spaces are occupied for only short periods.

Even in houses much economy may be obtained by recognizing that much of the space is only temporarily occupied. To insist even on 1,000 cubic feet of air space with renewal each 20 minutes is to demand an unnecessary waste of energy and money.

HEATING

The subject of ventilation is intimately associated with heating. The methods by which a house is heated have, it may almost be claimed, all to do with the distribution of the air within the house and with the withdrawal of used air and even the supply of fresh air.

Heat is imparted in three ways:

1. By radiation.
2. By conduction.
3. By convection.

Radiation—Air is transparent to heat. The drier the air the less is the heat which is retained by it. Heat passes through air and is reflected and absorbed by objects in its path according to their color, surface, and temperature. The intensity of radiant

heat varies inversely as the square of the distance from the source. A good example of radiant heat is the heat furnished by the open fire.

Conduction—The transmission of heat from one particle of matter to another in direct contact with it. No substance is absolutely non-conductive, but metals are far better than wood, woven materials or asbestos.

Convection is heat conveyed by liquids or gases in motion. Such gases and liquids become warmed and pass upwards and are

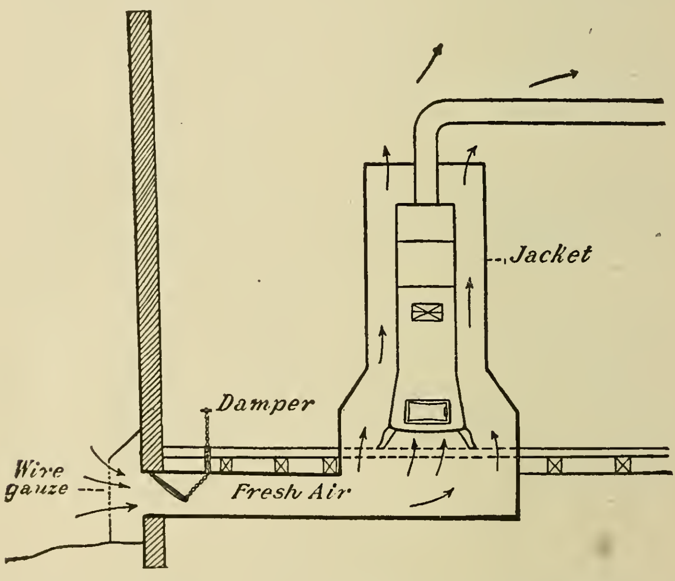


Fig. 27. Jacketed ventilating stove. (Harrington.)

in time replaced by other liquids and gases, which come in from the side.

Convection currents are set up by all heated subjects in a room, including the individuals themselves.

Open Fires and Stoves—Heating by radiation is illustrated by the use of an open fire or stove, though to some extent it is also heating by conduction.

The efficiency of the stove is increased by surrounding it by a cylinder which increases the amount of conduction from the stove and also sets up some convection currents (Fig. 27).

Heating by open fires greatly increases the cheerfulness and ventilation of a room but they are not an economical method of heating. Stoves are more economical, especially when sur-

rounded by a cylinder of sheet iron. This cylinder may be so arranged that fresh air may be taken in from the outside and warmed by conduction and applied to heating the room by convection.

Stoves consume much oxygen within a room and are very liable to give off carbon monoxid gas. This may be guarded against by insuring complete combustion (Fig. 28). In this connection it must

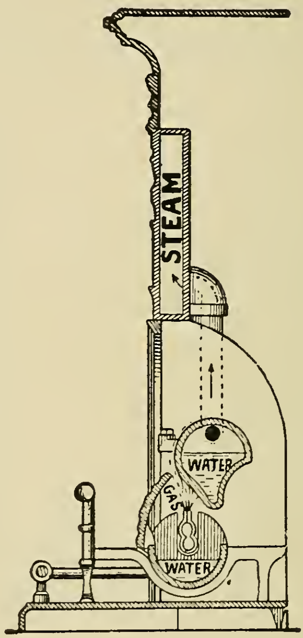


Fig. 28. Section of Backus' portable steam radiator for use with gas, insuring complete combustion and the supply of moisture to the air in the room. (Egbert.)

be remembered that red hot stoves may transmit carbon monoxid gas through their walls.

An oil stove is really preferable to a coal stove, for while it also discharges its products of combustion into a room, these, in the case of the oil stove, are carbon dioxid and water.

Houses may be heated from a central heating station in the house. These stations may be hot air furnaces, hot water furnishing systems or steam furnishing systems.

Hot Air Furnaces—Hot air furnaces possess enormous ventilating power. The heated air replaces or drives out the colder air within the house.

Hot Water Systems—In these systems the building is piped

with pipes which are filled with water and communicate with water heated in the furnace. Convection currents are set up in this water, which transmits this heat to all parts of the house. Vents for the discharge of air must be placed in the system and a return flow of the water also provided for.

Heating by Steam—In heating by steam there is also a system of pipes, which communicate with the boiler over the central heating station. Steam is evolved within this boiler and is conveyed by the pipes to all parts of the house. This method of heating by steam is called the direct method.

In the indirect method the steam pipes do not enter the room but the outside fresh air heated by passing over the pipes is then passed into the room.

The most satisfactory of these methods considered from the standpoint of expense, efficiency and all-round serviceability, is the hot water system. This system may also be more easily regulated to suit the extensive variations in outside temperature occurring through all the cold months of the year.

In any system of heating it is important to provide for the proper supply of moisture. Nothing is more deleterious to the healthy conditions of the mucous membranes of the respiratory passages of the individual than the abnormally dry atmosphere of the houses dry-heated. Provision should be made for keeping the relative humidity up to 50 or 55 per cent.

LIGHTING

Natural Lighting—In the usual house or building in the town or city, the daylight entering through the windows is sufficient during the day. In many buildings in the largest cities even in the day sufficient light from the sun is not obtained without assistance. In many such instances sufficient additional assistance is obtained by placing ribbed or, better still, prismatic glass either in the windows or constructing hoods of such prisms and swinging them as eaves or porchcovers above the windows. By thus refracting the light it is thrown directly into the rooms (Fig. 29).

Artificial Lighting—Artificial light must be depended upon in certain other buildings during the day and at night in all buildings.

For artificial lighting, until recent times, nothing better was known than oil or candle flames or more recently gas flames.

Flames—Every flame consists of 4 portions. The lowest portion is blue and gives no light. The middle portion is dark in color and consists of hydrocarbon generated from the oil candle, or in the case of the illuminating gas of the gas supplied. Next, the luminous part of the flame, which consists of incandescent particles of carbon which are passing outwards in a heated state having

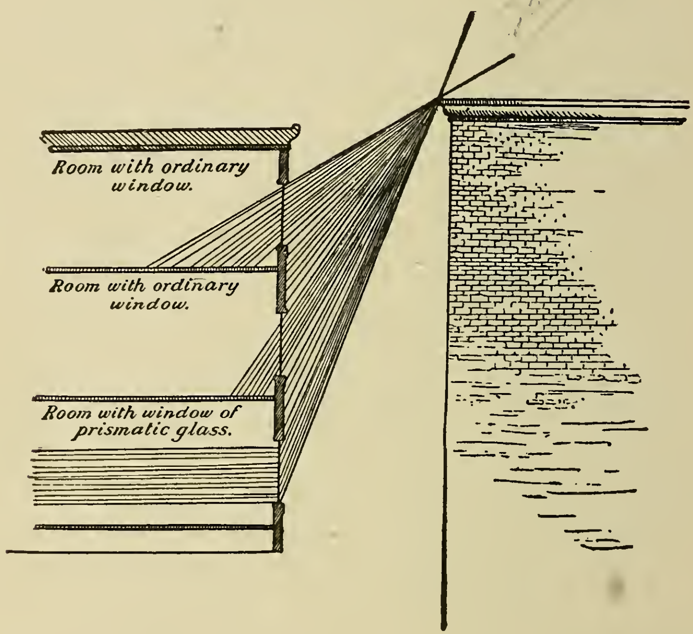


Fig. 29. Action of prismatic glass in projecting light. (Harrington.)

escaped complete combustion in the oxygen passing inwards from the outside space, which oxygen is insufficient to unite with the carbon of this portion of the flame. In virtue of its greater affinity with hydrogen the oxygen unites with it, thus furnishing the heat to illuminate the particles of carbon. Still more externally in the flame is a second colorless portion, in which portion, being nearer the supply of oxygen, there is sufficient oxygen to oxidize the carbon to carbon dioxid. If the area of the outside surface of the flame is sufficiently small, enough oxygen cannot be taken to unite with all the carbon and the unsatisfied carbon passes off as smoke. Defects in the burner or excessive richness may produce the same effect. If, on the other hand, the area is too large, there

may be a simultaneous combustion of the hydrogen and carbon of the hydrocarbons with no luminosity. This same end may be accomplished by the excessive supply of oxygen provided by the Bunsen burner.

Gas Burners—Gas burners are so designed as to give large surfaces and 2 forms are in use: the bat's wing burner, consisting of a narrow slit which spreads the gas in a flat, concentric sheet, and the fish-tail burner, which consists of 2 little holes side by side. The bat's wing burner is the best.

The Argand Burner—The Argand burner provides for a circular flame supplied through the center by means of perforations below in the holder for the chimney to allow an abundant supply of air.

The Welsbach Burner—The Welsbach burner consists of a Bunsen burner supplying the gas beneath an incombustible material which becomes intensely luminous in the heat of the flame. One of the commonest and best mantles is made by soaking a delicate cotton network in a strong solution of earth oxids (cerium, zirconium, lanthanum, and thorium). When lighted, the cotton burners give out more light with less expenditure of gas than even the Argand burners. Burners on the same principle may be used with kerosene. The combustion in these burners may be made complete with far less danger of the incomplete combusted products escaping into the room.

The following are the varieties of gas used for illuminating purposes:

Coal Gas—Coal gas is made by heating bituminous coal in fire clay retorts by which the compounds of hydrogen and carbon are transformed into gaseous and other products. By condensers and other purifiers it is freed from ammonia, hydrogen sulphid, tarry and other impurities. The purified product consists of 50 per cent of hydrogen, 35 per cent marsh gas, 60 per cent carbon monoxid and the remainder of ethylene and other hydrocarbons and nitrogen.

Water Gas—Water gas is made from coke or anthracite coal, steam and petroleum.

The coke or coal is placed in an air-tight cylinder lined with fire clay ignited and blown by a blast to a white heat. Then the air is suddenly shut off and steam is blown in. By the great heat

the steam is decomposed into hydrogen and oxygen. The oxygen unites with the carbon, forming carbon monoxid, leaving the hydrogen to pass in uncombined. The mixture is then carried to a carburetter chamber of fire brick, kept at red heat within which petroleum is injected and volatilized and mixed with the hot gas.

Relative Toxicity of Coal and Water Gas—The final product smells like coal gas, but has a very different composition. It is far more poisonous, as has been demonstrated in Boston by statistics of the deaths from gas when water gas was substituted for coal gas. It contains 30 per cent of carbon monoxid, 35 per cent of hydrogen, 20 per cent of marsh gas, ethylene and nitrogen.

The poisonous qualities of either coal or water gas are due to the carbon monoxid, only 0.4 per cent in the air is required to produce fatal results, but even less is fatal after long exposures.

Acetylene Gas—Acetylene gas is an unstable hydrocarbon $C_2 H_2$ mixed with air, 1:19. It is violently explosive. It is poisonous, but not to the same extent as coal gas. It produces unconsciousness without excitement and death after prolonged exposure. Burned in the ordinary way it smokes, but by using a thin slit and by forcing the gas through under pressure, it gives a very brilliant flame, 15 times that of ordinary gas.

Gasolene Gas—Gasolene gas is a mixture of gasolene vapor and air. The air is simply a diluent. The gas is generated and forced by supply pipes to the burners by an apparatus which requires little attention in contrast to acetylene. It is well suited to single houses.

Disadvantages of Gaseous Illumination—The use of gaseous illuminants possesses many disadvantages. First of these is the consumption of the oxygen in the room and the giving off of poisonous gases into the air of the room. These products are of least importance from candles or lamps, but are considerable from illuminating gas. They include carbon monoxid, sulphur dioxid, and ammonia compounds.

Second, among the disadvantages, are the danger of leaks and the collection of condensed water in the pipes which causes flickering. Flickering may be avoided by the use of drip cups. Gas fixtures should never be placed in draughts or over heaters.

Electric Lighting—Electric lighting entails none of these disadvantages. It in no way alters the air of the room. It imparts

little heat. Nothing has surpassed the tungsten or new nitrogen tungsten globe in the approach to ideal artificial lighting. The matter very directly affects health and the preservation of the eye, one of the most important possessions of man.

PLUMBING

Relation of Good Plumbing to Health—The importance of plumbing has unquestionably been over-rated. The suggestion that defective plumbing is injurious to the health is a strong one from the nature of the waste which plumbing cares for. As a matter of fact, dangerous bacteria are not transmitted easily by a defective system of plumbing. However, indirectly, poor plumbing may be a source of ill health. Bad odors from defects in plumbing or a knowledge of improper conditions in this regard may affect the appetite and thus seriously injure the nutrition of sensitive individuals.

Contamination of the Air with Bacteria with Defective Plumbing—Because bacteria may not easily be transmitted by defective plumbing from sewage, it does not mean they never are. That they may be, has been demonstrated by the plate experiments already referred to.

Conditions Constituting Good Plumbing—No system of plumbing should, therefore, be tolerated which leaks either liquid or solid matter or foul air or smells.

All fixtures on each floor should be in relatively a vertical line. The waste pipes should be accessible and pass in such a manner that they shall be in full view so that leaks may be easily detected. The important fixtures, such as bath tubs and water closets, should be placed where ventilation is abundant and free and where dependence upon artificial light is not altogether necessary. The ideal place is in an outer room furnished with a window through which fresh air and sun rays may easily enter.

The soil pipe is the pipe which connects the various waste pipes of wash basins and tubs and water closets with the drain pipe. They are, therefore, the vertical pipes running from the various floors to the cellar. They are preferably made of cast iron. The spigot end of one fits into the limb of another. The front should

be made tight by calking and then pouring melted lead down upon the oakum and pounding the lead tightly into the groove. Better still, perhaps, is to bolt the two pipes together. Each separate soil pipe should extend 2 feet above the roof of the house and they

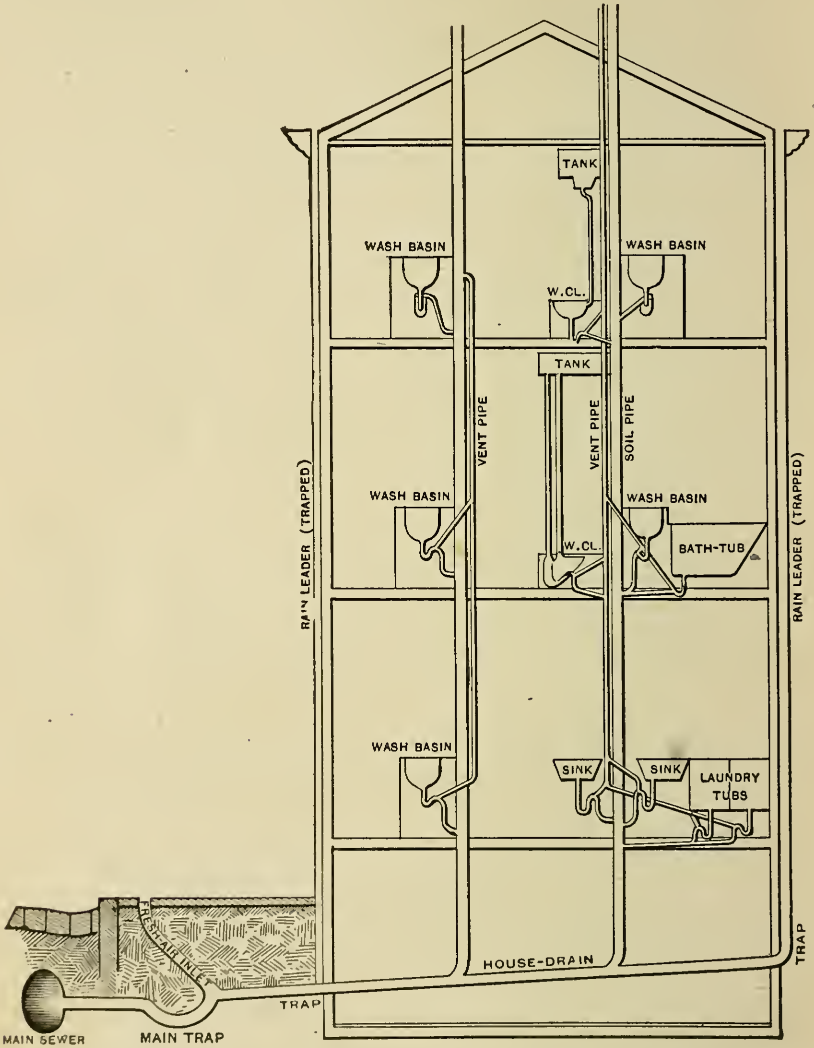


Fig. 30. Illustrating sewage-plumbing of a house. The traps of the rain-leaders at their junctions with the house-drain have been accidentally omitted. (Egbert.)

should not be covered with a cap or cowl. Whenever it is necessary to provide for a bend in a soil pipe, it should be done with an elbow piece and the unions made with Y pieces (Fig. 30).

The pipe connecting the bottom of the soil pipe with the sewer

pipe outside of the house running, therefore, with a tilt slightly off the horizontal is called the drain pipe. The drain pipe must be of iron and run to a joint external to the cellar wall and well away from it. The drain pipe may be suspended from the cellar ceiling or, if it can be buried, it may be placed beneath the cellar floor, but should, nevertheless, be accessible and have a pitch of ¼ of an inch to the foot and without lap. At the place where the

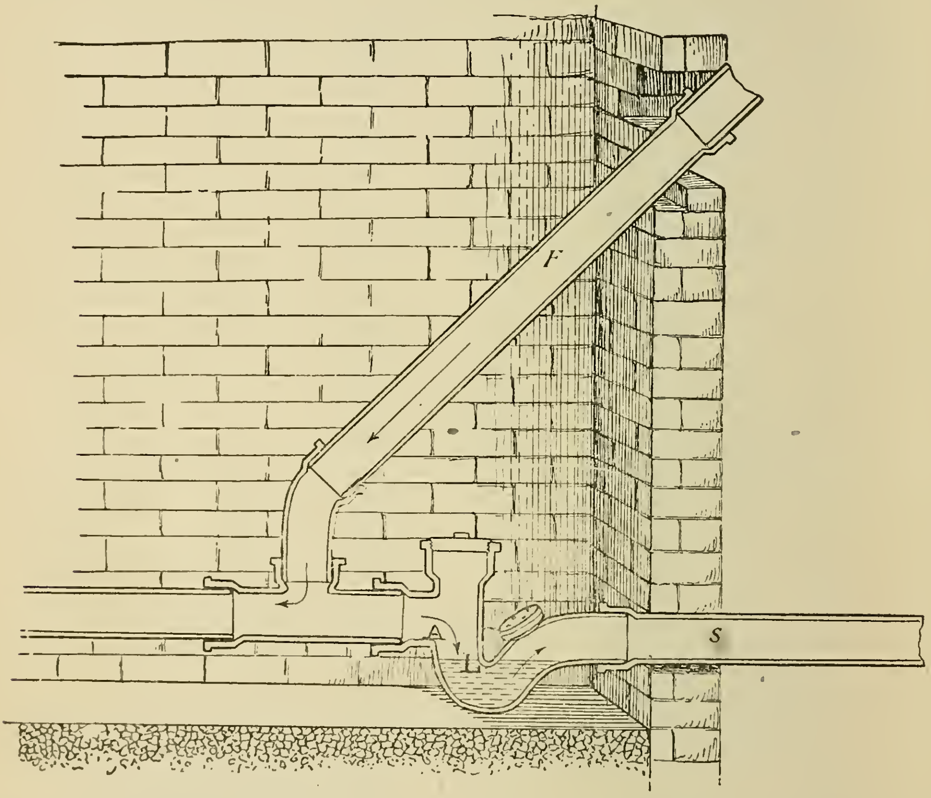


Fig. 31. Preferable arrangement of intercepting trap and ventilating pipe. (Harrington.)

drain leaves the cellar wall or at least just outside of the foundation walls within a manhole there must be an intercepting trap. The construction of the trap should be such that the outlet end of the trap is slightly lower (2 inches) than the inlet. The inlet end should be back-aired, preferably in front (the house side) of the trap. The pipe furnishing the connection with the surface air should be of the same diameter as the drain pipe (Fig. 31).

Figs. 32 and 33 represent proper and improper connections of another form of vent pipe.

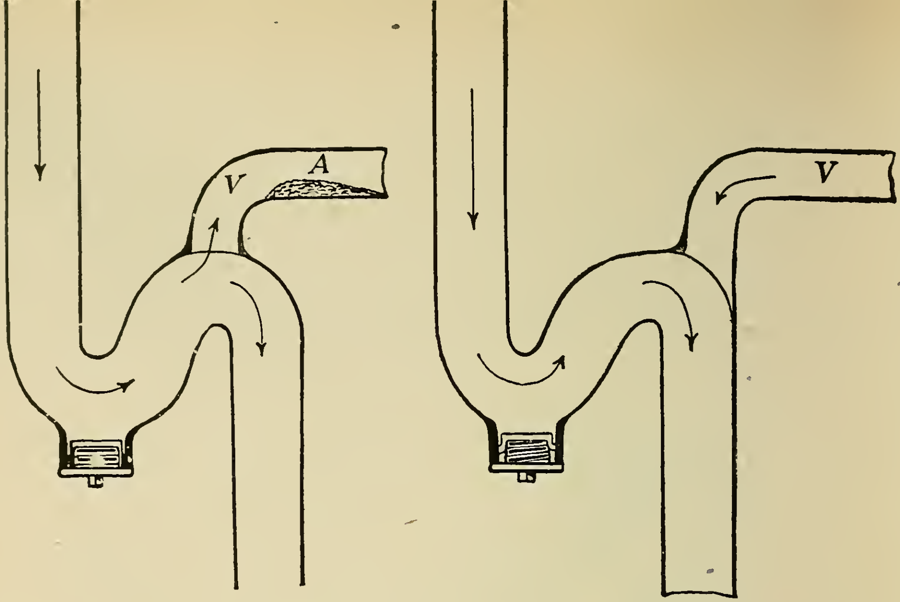


Fig. 32. Improper and proper positions of vent pipes. (Harrington.)

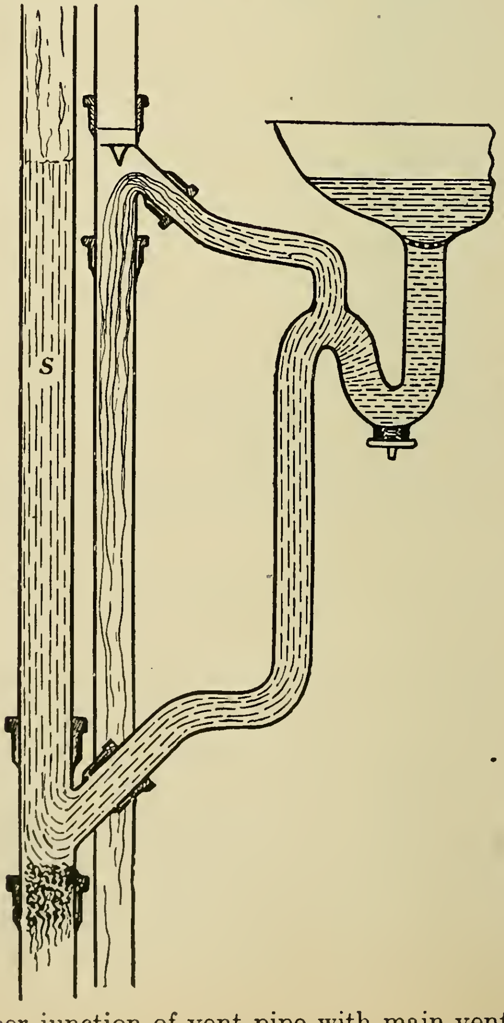


Fig. 33. Improper junction of vent pipe with main vent. (Harrington.)

By the seal of the trap is meant the depth of the water in a U-shaped trap above the highest horizontal line which passes without interruption from the inlet side to the outlet side of the trap. It should never be less than 1.5 inches.

Traps of many different shapes have been made. None is better

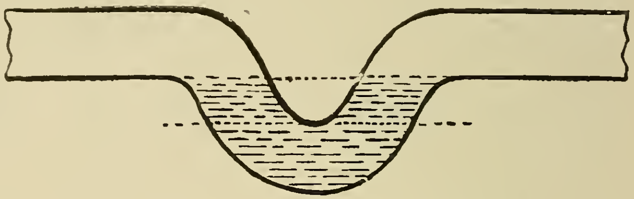


Fig. 34. Running trap. (Harrington.)

than the single running trap. Bottle traps, ball traps, bell traps and grease traps all have been designed for special purposes, but the simplicity of the U-shaped trap gives it superior advantages (Fig. 34).

SEWAGE

The Sanitas trap, invented by J. Pickering, though not so simple, possesses the advantages detailed with the legend Fig. 35.

With the invention of the water closet in 1810, the question of the hygienic disposal of sewage began to be first seriously considered.

The best form of water closet is the "Sanitas" (Fig. 36). It is provided with a syphon tank valve, a good flushing run, an efficient siphon pipe and it makes practically no noise. Other forms of self-siphoning closets are illustrated in Figs. 37 and 38.

Wash basins (Figs. 39 and 40), bathtubs (Figs. 41 and 42), and washtubs, are best made of iron with porcelain enamel.

Domestic and Industrial Sewage—With the invention of the water closet and the more general introduction of the public water supplies, the separation of domestic sewage, including the wastes from toilets, basins, bathtubs, kitchen sinks, and laundries, from industrial sewage composed of the wastes from establishments, like paper mills, tanneries, dye houses, and factories, etc., was no longer maintained. Both together constitute municipal sewage.

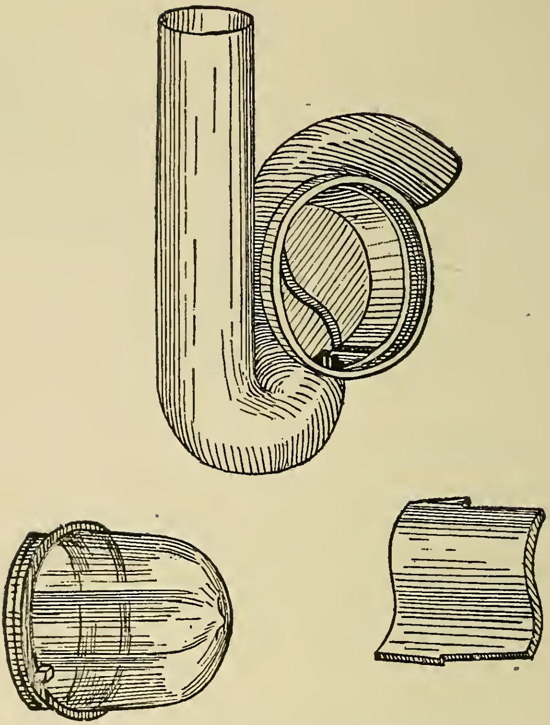


Fig. 35. Sanitas trap (taken apart) showing the deflecting partition within the chamber which permits of the passage of air above the water and throws back a volume of water sufficient to maintain a seal over three inches in depth, which resists evaporation for a long time and cannot be destroyed by capillary attraction. The trap is made proof against siphonage. When attached to fixtures with large outlets and quick discharge it is self-cleansing, even when ashes or similar unusual constituents of sewage are thrown into them. (Harrington.)

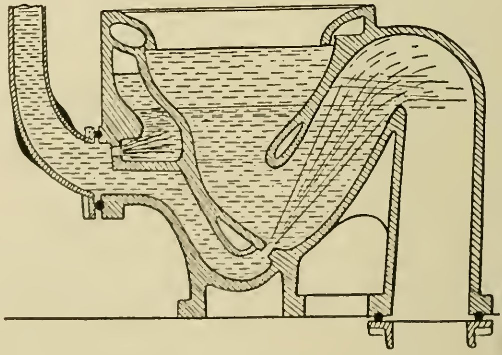


Fig. 36. Sanitas closet.

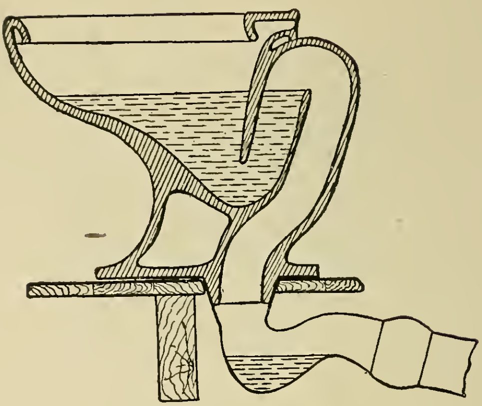


Fig. 37. Dececo closet. (Harrington.)

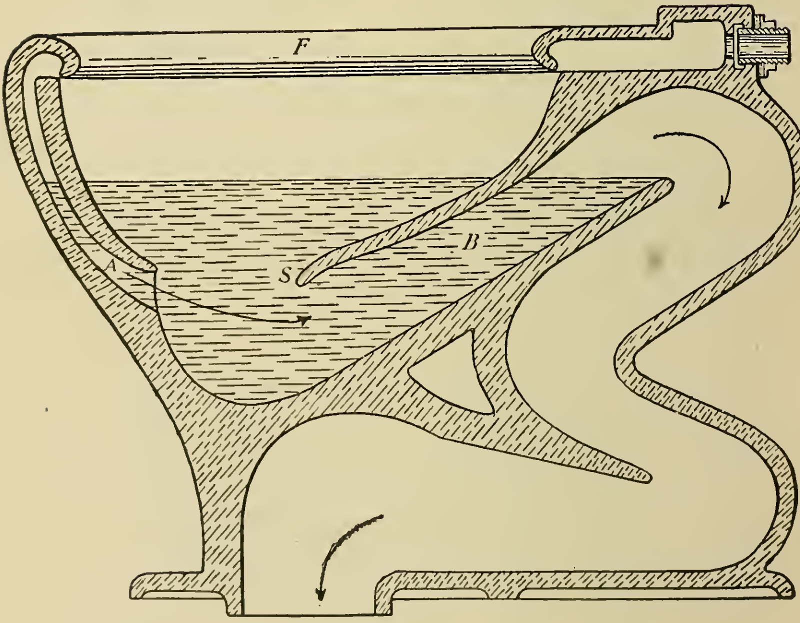


Fig 38. Siphon jet closet. (Harrington.)

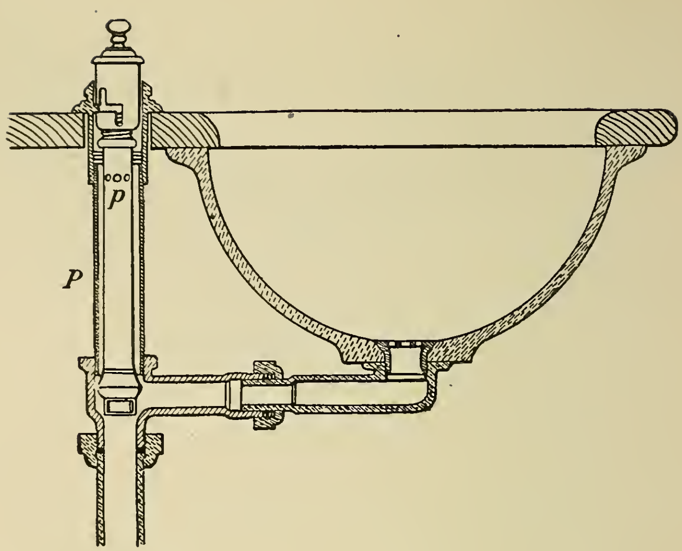


Fig. 39. Wash basin with standpipe plug and overflow. (Harrington.)

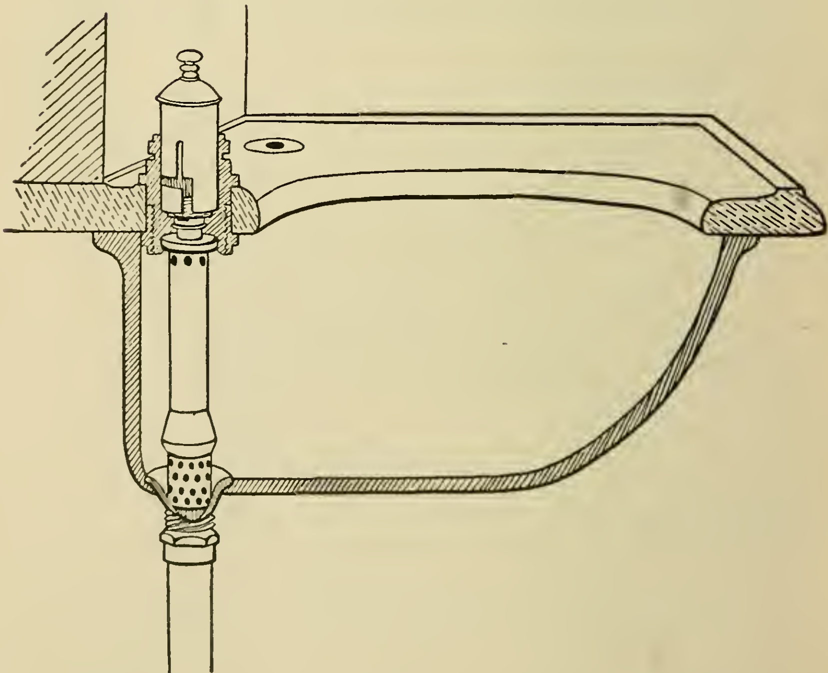


Fig. 40. Improved standpipe overflow. (Harrington.)

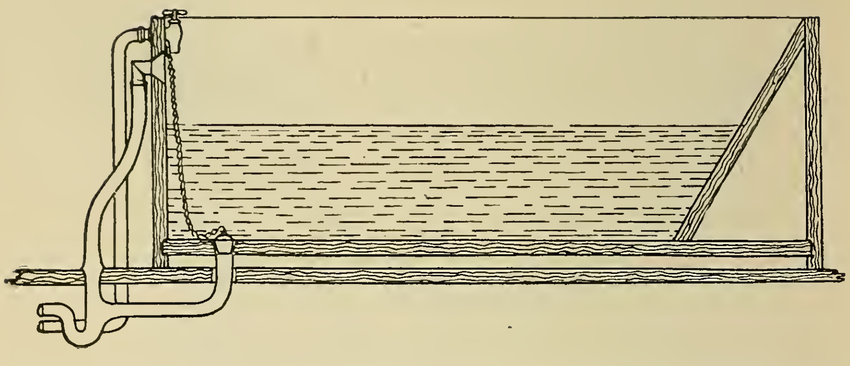


Fig. 41. Vertical section of commonest form of bathtub. (Harrington.)

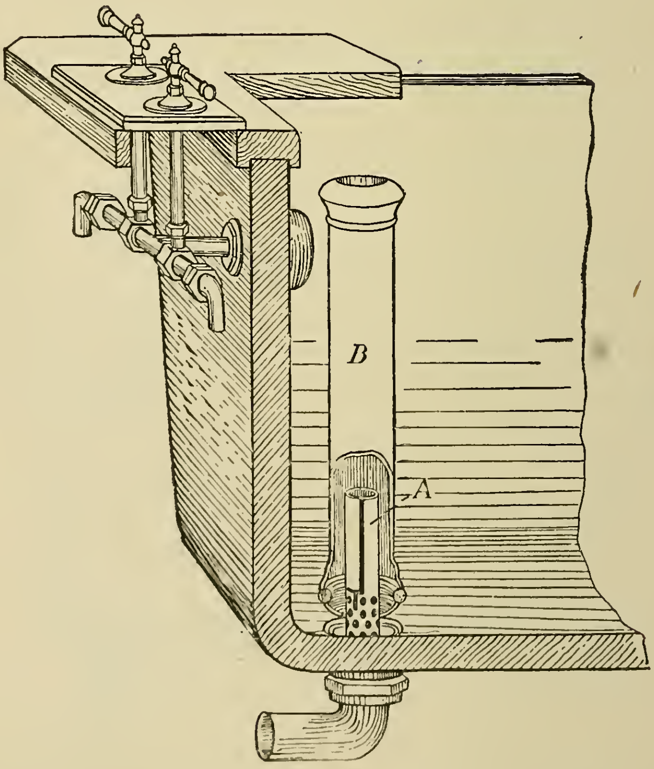


Fig. 42. Standing overflow and waste pipe. (Harrington.)

Manurial Value of Municipal Sewage—As long as domestic sewage was separated from industrial sewage, considerable use was made of the waste from human life for fertilizing purposes and in the minds of many the belief still prevails that municipal sewage possesses great manurial value. Victor Hugo has forcibly expressed this idea in "Les Miserables," beginning thus: "Paris casts 25 million francs annually into the sea and we assert this without metaphor by day and night. How so and in what way? For what object? For no object. With what thought? Without thinking. With what object? None. By means of what organs? Its intestines. Etc."

This statement declaring that Paris throws away wealth in golden dung sufficient to pay ¼ of the expenses of the budget is doubtless true. But on the other hand, at the present time it is not economical or hygienically desirable to separate from sewage those constituents of fertilizing value. In domestic sewage, where the water supply is abundant, the organic matter constitutes only 1 per cent and the sewage of Boston has been estimated to be worth about 1 cent per ton and that of New York even less. It is surely not worth its transportation in the absence of the possibility of this being arranged by sewers.

The Disposal of Municipal Sewage by Means of the Sewage Irrigation System—Of the various methods of disposing of sewage, the sewage irrigation system approaches closest to the most ideal and economical method of disposing of municipal sewage. Large sewage farms are provided for the purpose, and upon these the sewage is pumped. There are hundreds of such sewage farms in England and others in Germany, France, India, and America. The success of the farms depends much upon the temperature the year around. That is upon the number of crops which may be grown, the character of the soil, and the amount of rainfall.

No hard and fast rules can be made as regards their operation in relation to the amount of land to be set aside, for instance, per 1,000 people. In general in England, 2,000 to 10,000 gallons are applied daily per acre. In Madras where the soil is loose and the vegetation rank, 75,000 gallons may be received on an acre daily. The best soil for the purpose is one of sandy loam with fine interstitial spaces which will permit not too rapid percolation and within which the process of nitrification may go on thoroughly. A dense

clay soil may be rendered suitable by admixture of sand or lime and by tile underdraining. With a proper care the effluent should be clear.

The farm is laid out in broad ridges separated by furrows into which the sewage flows. The crops grow on the ridges between. At intervals of 6 feet, the whole farm should be naturally or artificially underdrained, so that the purified water in excess may drain off into the natural water courses. The city of Berlin has set aside a tract of 20,000 acres for its sewage farm. The yearly yield of grass per acre is 25 tons, equal in value to 5 tons of hay. The original cost of the farm was $13,000,000 and the entire plant yields annually a profit of $60,000, or ½ of 1 per cent interest, although the labor costs nothing except for the maintenance of the men engaged, who are condemned for minor offenses.

In Madras, where 8 crops a year may be harvested, 69 tons of grass or 25 tons of hay are obtained per acre. It must not be considered, however, that, although in cold climates, the crops cannot be grown in the winter, sewage is not disposed of by the natural forces of purification the year round.

Near Montreal, for instance, it was found that the sewage farm would act efficiently in disposing of the usual amount of sewage in January with a temperature of 20° F. Sewage farms have been proved to furnish no unhealthy conditions to those working upon them. At the Berlin works, in a population of 1,500, there was one death from typhoid in five years. At Gennevilliers, which receives sewage from Paris, there was no typhoid following an extensive outbreak in Paris.

As a source of profit, however, these farms cannot be considered a good investment. Certainly in arid sandy regions, which need artificial irrigation, they are more profitable, but in regions of the world where feasible conditions for irrigation sewage do not exist, it cannot be considered a good investment; and it is more economical to dispose of sewage in other ways. The waste of any valuable fertilizing material in communities, so situated that sewage farming is not advisable, by deliberately turning the sewage properly purified into water courses, must be regarded as so much spent for the health of the community. It is far better to allow other natural forces of conservation to provide for the return of the nitrogen to the air.

The Discharge of Sewage into Water Courses—In the large cities situated on rivers and on the sea, sewage is best disposed of by discharging it into either of these bodies of water. It becomes so diluted that only under exceptional and quite avoidable circumstances does it become a nuisance much less a danger to the health. There must be, however, sufficient current to rapidly dilute the sewage. With a movement of water of less than 1½ miles per hour there are likely to be deposits made which become a nuisance. In inland rivers the sewage is best delivered to some point below the city or town.

Studies by the Massachusetts State Board of Health have justified the conclusions, aside from all reference to objections caused by the manner of discharge of sewage and considering only the question as to whether objectionable conditions exist in the various streams into which sewage is discharged, that where the flow of a stream exceeds 6 cubic feet per second per 1,000 persons discharging sewage, objectionable conditions are unlikely to result.

Purification by Sedimentation and Chemical Precipitation—In many places, however, a partial purification of sewage before its discharge is possible. This may be accomplished by sedimentation and chemical precipitation. Sewage is rendered far more fit to discharge into water courses by the removal of solid material in suspension in it. If this is done the natural forces of the purification of the remainder are relatively and quickly efficient. Practically, therefore, any sewage disposal system of any size should be and is provided with settling tanks. In these tanks, precipitation is hastened by chemical treatment of the sewage. The effluent liquor after such treatment will contain only 1/3 as much suspended matter as the same sewage after passing through only the settling or septic tank. The sludge or precipitate, it is true, may be three times the amount after the exposure of sewage to the complete process in a septic tank, but the effluent fluid is nevertheless clear.

The sewage flows first through screens which remove the coarser matters. It is then mixed with alum lime or ferrous sulphate. Alum and other soluble salts of aluminum in the presence of lime or ammonia form a very gelatinous precipitate. With an excess of alum the effluent may be acid, but will not contain the unsightly

black compounds of sulphur or iron. Treatment with one ton of precipitate per million gallons costs about $17 per million gallons.

At the Lawrence Experiment Station, during 5 years (1893-1897), sewage was treated with sulphate of alumina (1,000 lbs. per 1,000.000 gallons) and sedimentation 4 hours. This treatment removed 66 per cent of the total organic matter and 78 per cent of the organic matter in suspension, and 68 per cent of the bacteria and 59 per cent of the fatty matters. The sludge after such method of precipitation is most commonly pressed by hydraulic presses and disposed of by burying or filling in of lowlands.

Filtration of the Effluent from Sedimentation Beds by Sand Filters—The filtrate from such sedimentation tanks is then in a much better condition to discharge into water courses or, more ideally, it may be filtered through precisely the same kind of sand and gravel filters which are used for purifying drinking water. These filters care for 75,000 gallons per acre daily. Such sand filters have been in operation at the Lawrence Experiment Station for 20 years. The effluent is a clear, highly nitrified water containing a minimum amount of unoxidized organic matter and a small number of bacteria.

The Bacterial Purifiers in Water—The purifying agents are the anaërobic bacteria which soon establish themselves in the interstices of the filter. In order that both anaërobic and aërobic bacteria may do their work, it is important that filtration should be intermitted with aeration of the filters at intervals.

It should be remembered that the action of these filters, in the presence of some kinds of manufacturing plants, with their sewage substances, such as arsenic or large amounts of grease, which are inimical to bacterial growth, is interfered with. Special provision must control the sewage from such plants. Nearly 30 municipalities dispose of their sewage through intermittent sand filters. The injurious substances should be submitted to proper preliminary elimination or treatment.

Contact Filtration—When proper filtering material is not available, as in England, where sandy soil is the exception, sewage may be purified by the process of contact filtration. Filters for this purpose are simply large beds of coke or other coarse material with retaining walls and tight bottoms and with outlets which can be closed. Sewage is applied in doses until the filters are filled

to the surface. It is then allowed to stand and after the period of standing, during which the organic matter is subjected to bacterial action, the water is slowly drained away. Seven hundred thousand gallons per acre at a depth of 5 to 6 feet may thus be treated daily. Its rate of filtration is, therefore, 10 times that of sand filters. Systematic resting of the filters for 1 week in every 6 is advised. Preliminary treatment to remove the coarser materials is advisable.

Trickling Filtration—Still another form of purification of sewage by bacterial action is by means of the trickling filters. These are constructed of stones ¾ inch to 1 inch in diameter, broken stones or even cinders 5 to 10 feet in depth. The sewage must be distributed evenly over the surface by an automatic sprinkling device. It filters through rapidly and, because of the good aeration of these filters, there occurs a quick oxidation of the putrefying matter, while the larger body of stable matters, and matters rendered stable by filtration, are allowed to pass through. The changes accomplished are essentially chemical. Trickling filters cannot be regarded as substitutes for sand filters which remove practically all the matter in suspension.

They are subject to the disadvantage in comparison to contact filters in that they require a head of water of 8 feet for proper distribution over the surface of the filter. The contact bed is far more inconspicuous and compact, produces less odor, does not breed flies and adapts itself to the irregularities of the flow into it.

The Complete Destruction of Organic Matter in Sewage—It will be appreciated from the description of these various methods of sewage purification that the essential process involved is the adoption of some means of retention of the sewage which will permit of the biological activities of both anaërobic and aërobic bacteria. Both these forms of bacteria perform definite action upon the sewage. The presence of the anaërobic bacteria is essential, and certainly the presence of oxygen is also necessary. Attempts have been made to bring about the complete destruction of sewage apart from filters.

Cameron Septic Tank—Such attempts at destruction of sewage are represented by the Cameron Septic Tank. The initial plant at Exeter consisted simply of a single tank 64 feet by 18 feet by 7

feet deep. The sewage enters the tank slowly through inlets 5 feet below the surface. The sewage enters the tank and passes through sufficiently slowly to allow all organic matter to settle out and be worked over by the bacteria until it is destroyed. The organic matter in solution is subjected to the same action. In practice about 10 to 20 per cent only of the organic matter is destroyed.

In such a tank the anaërobic bacteria are the chief agents in the destruction of the organic matter. A modification of this tank which gives them a still further opportunity for activity and submits the remainder of the sewage to oxidative processes is more successful.

The Nuhoff Tank—The Nuhoff tank, based upon the conception of Dr. Travis, which was worked out at Lawrence, Massachusetts, accomplishes a more complete purification of sewage. This tank consists of 2 cylinders 30 feet deep with conical bottoms. These cylinders open into the bottom of a rectangular tank through which the sewage passes. The solid particles in the sewage settle into the bottom of the cylinders. Within these cylinders the sludge is worked over by an anaërobic bacteria, the gas being diverted from the upper tank by baffles. The sludge is held in the lower chambers for a series of months, and when necessary forced out through their bottoms and spread out on beds, upon which it dries quickly, and is then removed to the place of final disposal. It is then without odor. The main body of the sewage passes over the 2 cylinders and on to some form of filter for further purification by means of oxidative processes.

The principle then virtually amounts to the separation of a large part of organic matter by a settling process and the destruction or radical change of a large part of the separated matter by means of the anaërobic bacteria and the purification of the remainder by chiefly the biological oxidative processes.

The Waring System for Separate Houses—On a small scale this method of purification is accomplished by the Waring system. In this system the sewage is discharged through a screen which takes out the paper and other non-oxidizable substances into a reservoir. It empties into a reservoir below the screen through a U-shaped trap.

The reservoir is emptied when it becomes filled by means of an

automatic siphon. It is thus intermittently emptied and time is allowed for the action of the bacteria purifiers, anaërobic and in part aërobic. From the tank the sewage, having been worked over in this manner, flows either into tile pipes arranged in rows and set 10 inches below the ground, or evenly upon the surface of the ground, where it causes no odor or unsightly appearance and where its purification becomes complete.

HYGIENE OF THE ORAL CAVITY

In the section upon bacteriology the part which bacteria play in the destruction of the gingivæ was emphasized. The whole subject of the hygiene of the mouth was summed up briefly in the phrases "efficient drainage of the immediate environment of the teeth" or "cleanliness of the oral cavity."

It is desirable now to further elaborate this subject and to recognize the associated influence of certain purely mechanical factors upon the peridental membrane. The progressive and gradual destruction of this membrane is a consequence of an associated inflammation induced within it, both mechanically and bacteriologically. Such an inflammation produces not only serious consequences, but also a chronic suppurative process between the teeth and the peridental membrane surrounding them. In the consideration of the subject of the hygiene of the mouth, nothing deserves greater emphasis than the fact that the health of the teeth depends more upon the health of the peridental membrane than upon any other single factor.

The fibers of the peridental membrane, passing in several well defined sets of fibers from their attachment within the cementum surround the teeth, pass between the teeth, and between them and the bone of the alveolar ridges. They must be regarded as forming so many supporting slings for the teeth. More than this, the peculiar combination of toughness and elasticity of this membrane, and its sharp edge at its free border where it immediately surrounds the teeth, enable it to maintain its form in such a manner that under normal conditions it sheds fluids and suspended matter within the mouth from off the teeth. This function is so efficiently performed that, when the teeth are normally formed and bear the

proper relation to each other, they may be preserved without decay or any recession of the gingiva until old age. This result may be achieved even in the absence of any other care than the most superficial cleansing, such as merely rinsing out the mouth.

In the normal denture each tooth comes into contact with the tooth next to it at one point called the point of contact. The gingivæ in each space between the teeth, called here the septal gingivæ, normally reach up to or almost to the contact points and slope down on each side, from the crest of the septal gingivæ extending between the contact points. The gingivæ become attached to the cementum of the teeth by the fibers of the peridental membrane a short distance beneath the free margin of the gingivæ. This free margin of the normal gingivæ is sharp, almost knifelike. Between it and the line of attachment of the peridental membrane a space exists completely surrounding the teeth, in which there is no attachment of the gingivæ to the teeth. This space is termed the subgingival space. The area upon the adjacent sides of the teeth below the line of the free margin of the gingivæ is called the septal space, and the areas in front and behind the vertical line of the contact points between the line and the free margin of the gingivæ and the occlusal surface of the teeth are called the buccal and lingual embrasures. (Figs. 43, 44, 45, 46.)

These surfaces are so formed that the secretions of the mouth with their suspended solid particles slide easily off of the teeth and the gingivæ.

As has been mentioned, dental caries is primarily caused by the action of the acid produced by the acid-forming bacteria upon the teeth, but these acids will not be produced in sufficient amounts unless the acid-producing bacteria can establish themselves in recesses or pockets where with them there can also collect deposits of food débris upon which the bacteria may live, and thus produce their life products. Such deposits never occur upon mucous surfaces, but may occur in either defects or fissures in the teeth themselves or in corners between the teeth and the gingivæ when the abnormal relations exist between the teeth themselves and between the teeth and the gingivæ. Again these deposits may occur in pockets produced as a result of destruction to the gingivæ. A defect once started in the surface of the enamel, or even a roughen-

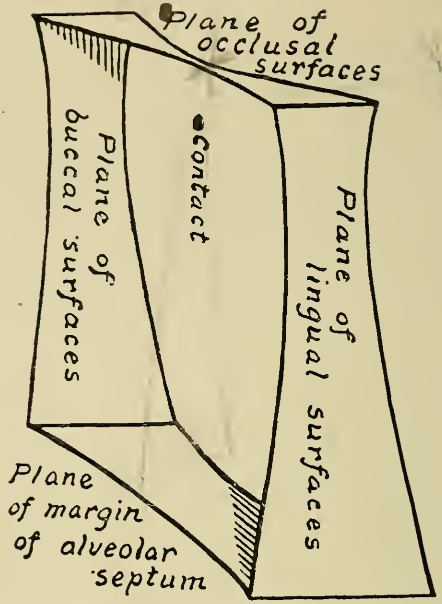


Fig. 43. Diagram to illustrate shape of interproximal space. If the rectangular frame is placed between two spheres which are in contact at the point indicated, the space within the frame and between the two spheres would be that of an interproximal space between the bicuspids and molars, which might be described as a rectangular section of a biconcave sphere. (Black.)

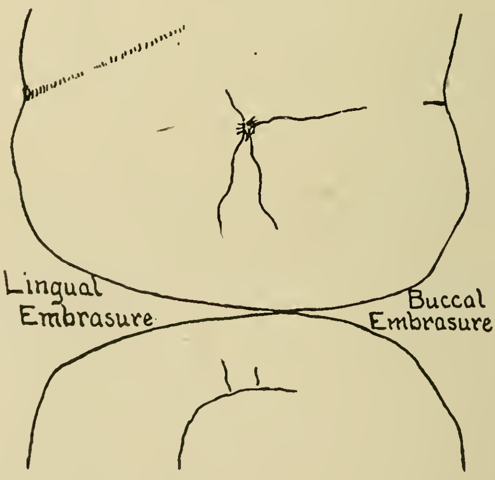
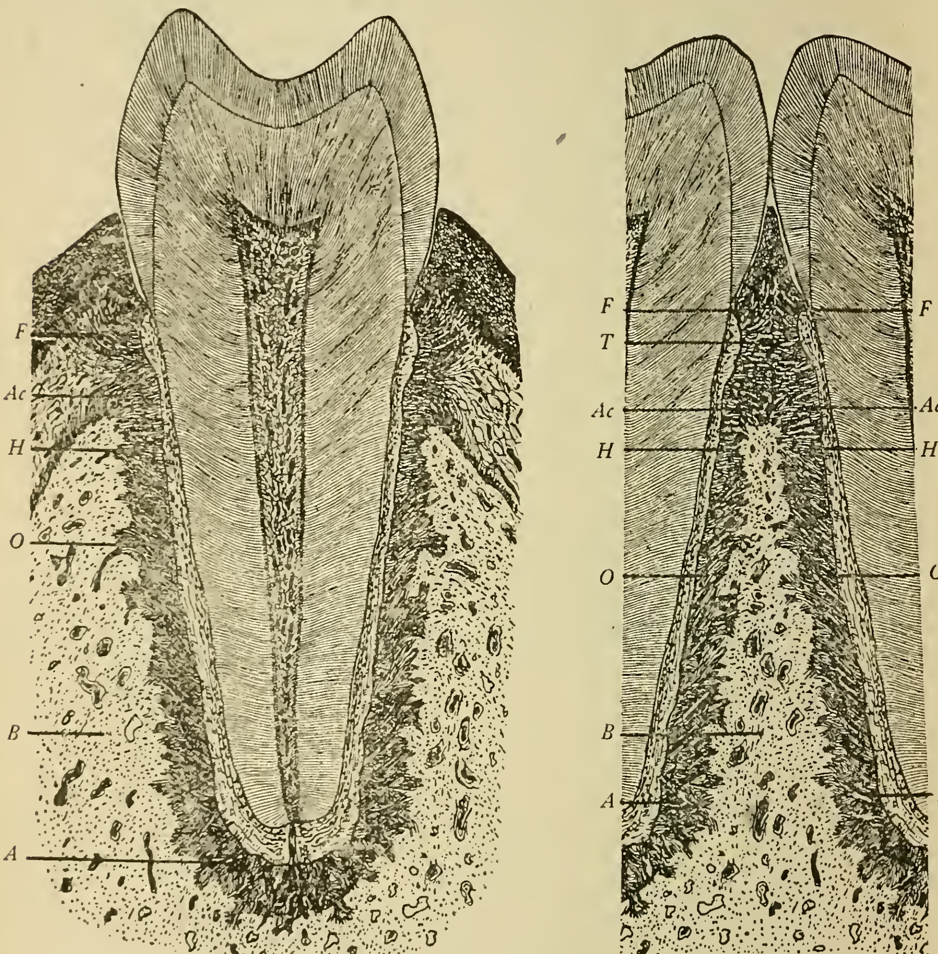


Fig. 44. Diagram to illustrate the relation of the embrasures to the point of contact. The portion of the interproximal space which is normally open (to the occlusal of the septal tissue), is divided by the point of contact into a buccal embrasure and a lingual embrasure. (Black.)

ing of the surface once produced, will gradually become deepened and in itself constitute a place of lodgment for bacterial breeding deposits.



Figs. 45 and 46. Diagrams illustrating groups of fibers of the gingivæ and peridental membrane. Fig. 45. Buccolingual section through a bicuspid tooth and investing tissue. F, Free gingival group of fibers. ac, Alveolar crest group of fibers. H, Horizontal group of fibers. O, Oblique group of fibers. A, Apical group of fibers. B, Bone of alveolar process Fig. 46. Mesodistal section through two bicuspid, one septal, tissues. F,F, Free gingival group of fibers into septal gingiva. T, Trans-septal group of fibers from tooth to tooth. ac, ac, Alveolar crest group of fibers. H,H, Horizontal groups of fibers. O,O, Oblique group of fibers. A,A, Apical group of fibers. B. bony septum of alveolar process. (Black.)

Such primary defects in the teeth and alterations in their normal relations with themselves and the gingivæ constitute one important class of etiological factors in the destruction of the teeth. Aside, however, from this direct action, when these deposits occur

upon the gingival border, they provoke inflammation in the peridental membrane and an inflammation leading to its destruction and separation from the cementum. Such a separation may not only be responsible for the formation of pockets surrounding the cementum which may lodge the acid-producing bacteria, but for the formation of pockets with constantly suppurating walls so that the cementum becomes bathed continually in pus. Such a condition once started becomes a vicious circle and reacts upon the peridental membrane upon one side, causing its continued destruction or deformation, and upon the other side it acts upon the cementum, causing a continued separation of the peridental membrane.

The denuded cementum is sufficiently porous to absorb and to become more or less permeated with the products of the putrefaction within the pockets surrounding it. This increase in the porosity of the cementum contributes to the chronicity of the process. The peridental membrane also becomes detached from the alveolar process and this detachment becomes the principal factor in an absorption of the alveolar process, which also regularly takes place.

The alveolar absorption begins opposite the place on the cementum from which the peridental membrane is detached. With the detachment of the peridental membrane from the cementum there is also a detachment of the cementoblasts and with their detachment a death of the cementum. Cementum differs from all other bone in the body. It depends entirely for its life and power of repair upon the cementoblasts of the peridental membrane. It is a non-vascular tissue. When the cementoblasts are detached its corpuscles die, whether the pulp is alive or not.

This train of events, an inflammation of the peridental membrane, its progressive detachment from the cementum, the death and increased porosity of the cementum and the absorption of the alveolar wall of the tooth follicle, in fact of the alveolar process itself, leads to a gradual progressive loosening of the teeth, until they can no longer be used for mastication and finally fall out.

The whole process is one which is quite different in its main consequences from the causes of dental caries acting directly on the teeth. It must be regarded, however, as not only most serious in its power to destroy the teeth, but also because of its power to destroy life. Too great emphasis cannot be laid upon the

danger coming from the invasion of the body in general by the pyogenic microörganisms thriving in the pus pockets formed by the detachment of an inflamed peridental membrane.

A consideration, therefore, of the hygiene of the mouth must include as one of its most important subjects the prevention of inflammations of the peridental membrane.

Thus far there have been considered two rather distinct causes leading to the destruction of the teeth. First, those leading rather directly to the destruction of the teeth and which act upon localized portions of the teeth and which produce carious cavities of the teeth. Second, those causes producing a primary change in the peridental membrane which leads to chronic suppuration around the teeth and the destruction of the whole denture.

One of these processes may be responsible for the other and both may result from the same etiological factors. They account for two definite pathological conditions within the mouth which are sufficiently separated from each other to constitute pathological entities. They are, namely:

1. Dental Caries.
2. Chronic Suppurative Gingivitis.

In addition to the above there is a third series of pathological conditions, which owe their origin to inflammation beginning in the dental pulp. Pulpitis and the death of the pulp is, however, so frequently secondary to dental caries that it might perhaps be better to classify it, and the train of events following it, as a subdivision under dental caries. Nevertheless, it is by no means always secondary to dental caries. This fact and the very special course of events following pulpitis warrant the consideration of pulpitis as a third group of pathological entities arising in the mouth in association with the teeth.

In brief, pulpitis is most frequently due to direct infection of the pulp from a carious cavity in the tooth. The dental pulp may become inflamed or killed by either a mechanical or thermal shock.

While a pulp may remain necrotic and inclosed for indefinite periods without giving rise to serious consequences, it by no means always does so. The more serious train of consequences frequently following acute pulpitis, and less frequently death of the pulp, is a collection of pus around the apex of the root of the tooth

and a detachment of the peridental membrane in this location. It is a detachment, however, which does not show the same tendency to spread in the direction of the occlusal surface of the teeth, as much as a detachment beginning at the free margin of the gingival processes shows a tendency to spread in the direction of the roots of the teeth. The usual direction of the inflammatory process is externally through the bony canals of the alveolar process. This method of extension soon results in the formation of an abscess beneath the alveolar periosteum, and, depending upon the promptness of proper execution of the pus, the subsequent course of events is either the resolution or the formation of a chronically discharging fistula leading down to the suppurating pulp and walls of the cavity surrounding the apex of the root, or in more unfortunate cases an acute osteomyelitis of almost any degree of severity with severe systemic infection.

The above brief outline of the inflammatory processes originating in connection with the teeth indicates the prophylactic precautions which are necessary to preserve a healthy condition of the teeth. They concern the prevention of the accumulation of any food or other material, including the deposits from the oral secretions, such as salivary or serumal calculus, upon the teeth or in the crevices between them. It also concerns the strict avoidance of any repeated trauma, or other cause of inflammation of the peridental membrane, or thermal, or mechanical shock to the pulp. As has been said, a normal mouth receiving a minimum attention, or the mere rinsing out of the mouth after meals, may suffice to keep the mouth and the gingiva normal for life. For the vast majority, however, a more scrupulous care is necessary. The following rules may be laid down as sufficient for the average patient:

1. Previous to the eruption of the teeth the mouth of the baby needs no special cleansing. The whole care at this period should be devoted to the mother's nipples, or the rubber nipple in case of a bottle-fed baby.

2. As soon as the deciduous teeth have erupted, the teeth should be cleansed with a brush after each meal, at least after breakfast and the evening meal. As soon as the permanent teeth have erupted, the use of a syringe should be added to that of the brush

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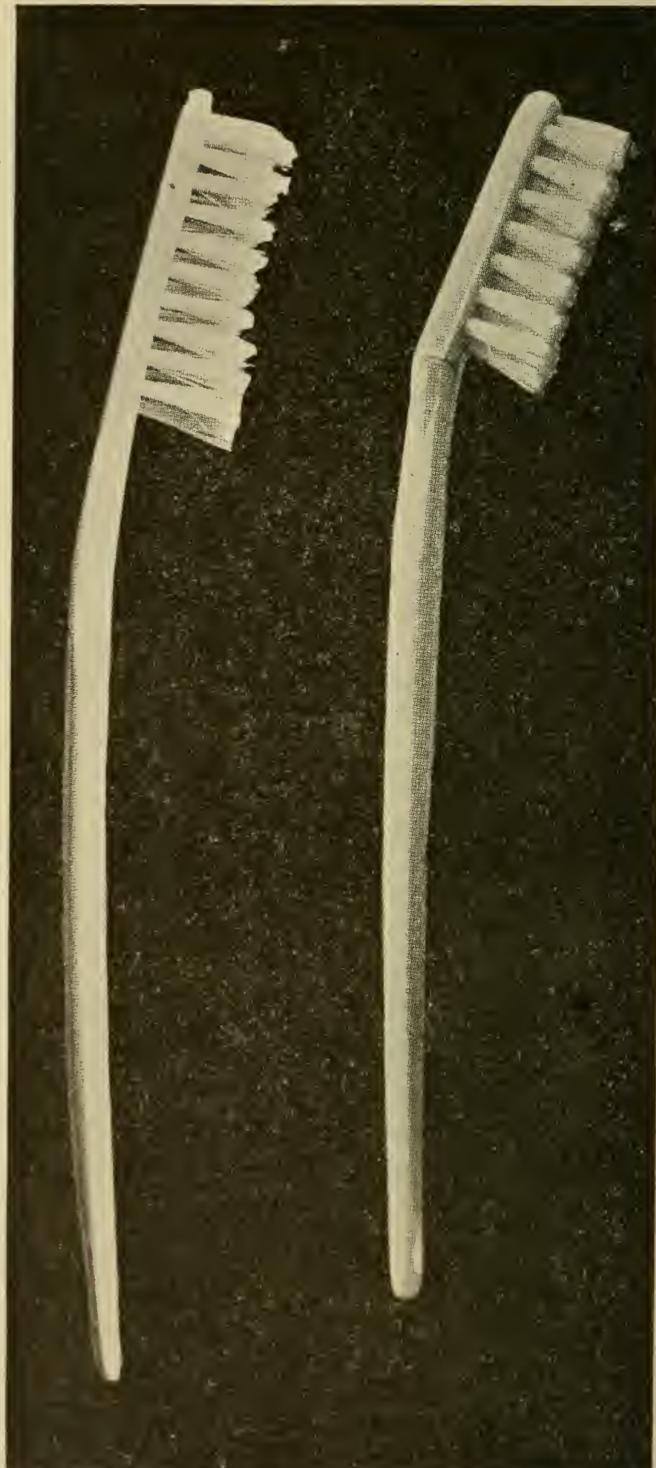


Figs. 47 and 48. Two tooth-brushes, actual size. Fig. 47 is a splendid brush This is the best form for most persons. Fig. 48 is a similar brush with a greater angle, and is especially good for reaching the lingual surfaces of the lower incisors

in order to give a more thorough cleansing of the spaces between the teeth and the subgingival spaces.

3. For cleansing purposes antiseptic and tooth powders or

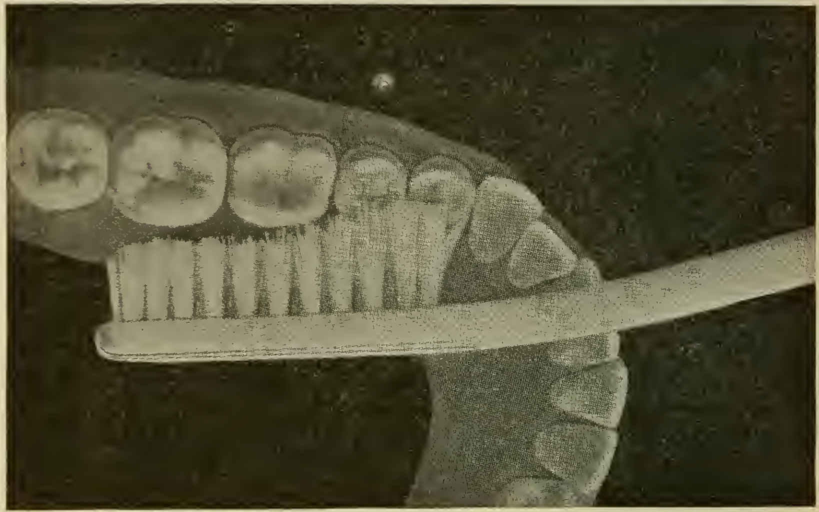


Fig. 49. This shows the position of the brush for the lingual surface of the lower molars. While the brush must be held diagonally to the line of the arch, the movement should be the same as on the buccal side. The brush should be placed on the gum and should then be swept occlusally over the gingiva and teeth. (Black.)

pastes are superfluous. Water of a tepid temperature is quite sufficient.

4. Great care is necessary in selecting a brush of proper size

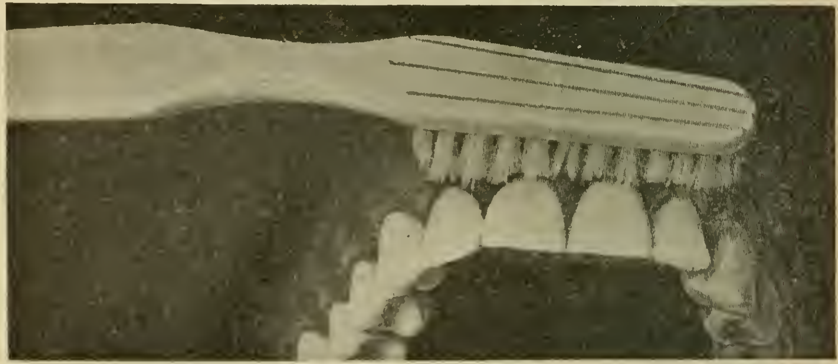


Fig. 50. The brush is shown in the proper position on the gum for the motion downward in brushing the upper front teeth. (Black.)

and adapted in its shape to the individual. The majority of brushes are too-large. Care should be exercised to select a brush

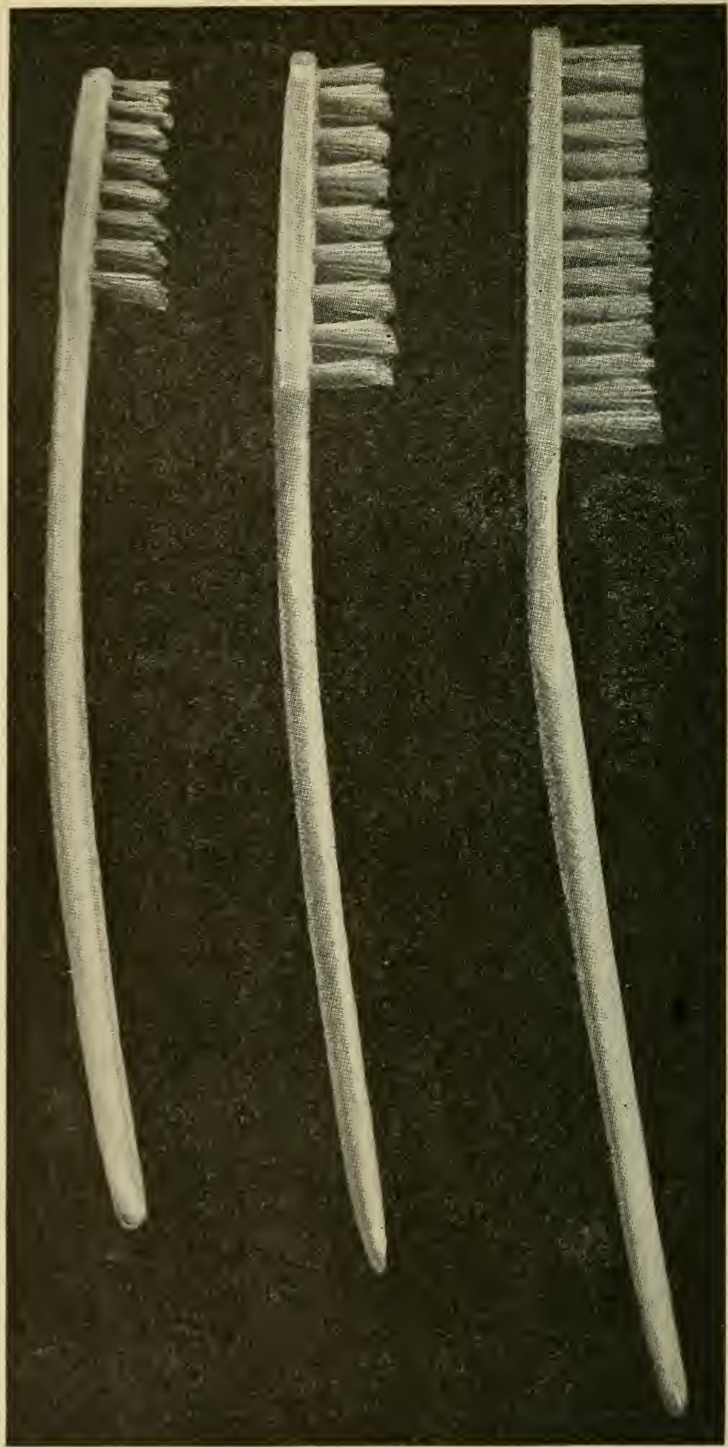
small enough to permit of its free movement in the mouth. As a rule, the brushes sold as youths' are to be preferred for adults. (See Figs. 47, 48, 49 and 50.) The bristles should not be too closely set, there being nearly as much room between the rows of bristles as the individual bunches of bristles themselves occupy. (See Figs. 51 to 53.) A brush of medium softness is preferable. It should have a degree of softness which will permit of vigorous use upon the gums without causing pain. In some mouths the third molars cannot be reached with a brush unless the bristles on the distal end of the brush are cut very short. (See Figs. 54 and 55.) In some instances a brush must be selected with a small separate tuft of bristles at the end which may be carried over the occlusal surface of the third molar and thus reach its distal surface. This may be the only manner in which this tooth may be successfully cleaned in some mouths.

5. The teeth should be cleansed in a systematic manner. It makes little difference what routine is adopted, but it is of importance that no teeth or surfaces should be neglected.

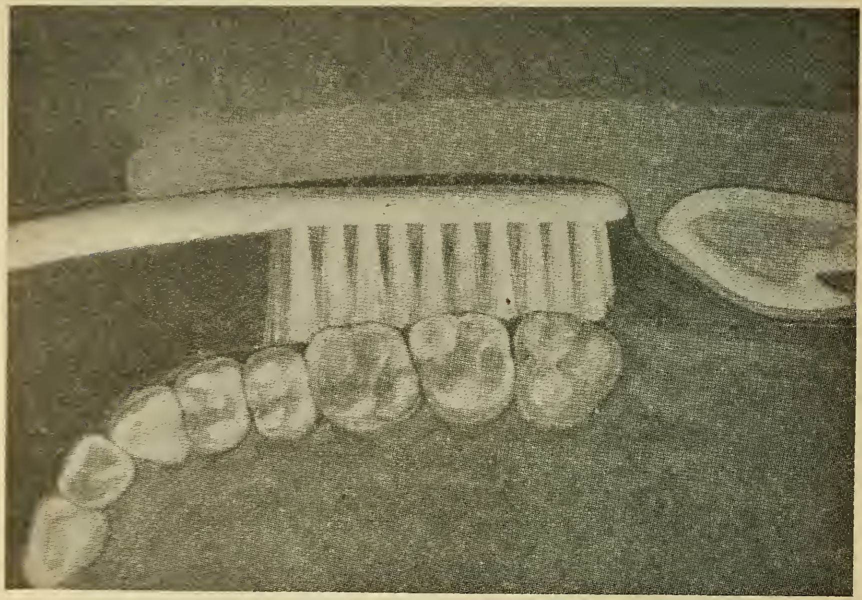
6. The movements of the brush should be rotatory when the labial or buccal surfaces of the teeth are being cleansed. The ends of the bristles of the brush should be made to describe circles around the long axis of the handle moving in a direction from the alveolar process over the gingivæ toward the occlusal surfaces of the teeth. Much the same movements will clean the lingual surfaces of the molars. When the lingual surfaces of the bicuspids and incisors are being cleaned the brush should be introduced over the occlusal surfaces of the teeth, and the lingual surfaces cleaned by a series of pulls in the direction of the handle of the brush. The lingual surfaces should be cleaned by the brush when it is pulled outward in the direction of the occlusal surfaces (Figs. 56 and 57).

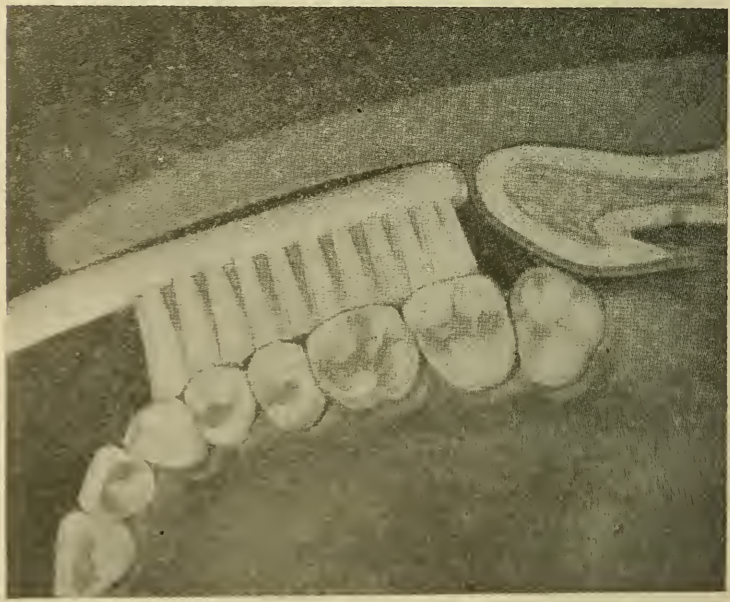
The occlusal surfaces of the teeth need little cleansing as a rule, but it is desirable to rub them with the brush by an in and out movement in the direction of the long axis of the handle. After cleansing the teeth the mouth should be thoroughly rinsed out with water forced between the teeth from the lingual to the labial and buccal sides. The brush should also be rinsed and hung up to dry.

7. Of equal importance with the use of the brush in the cleansing of the teeth is the use of the syringe. A syringe should be

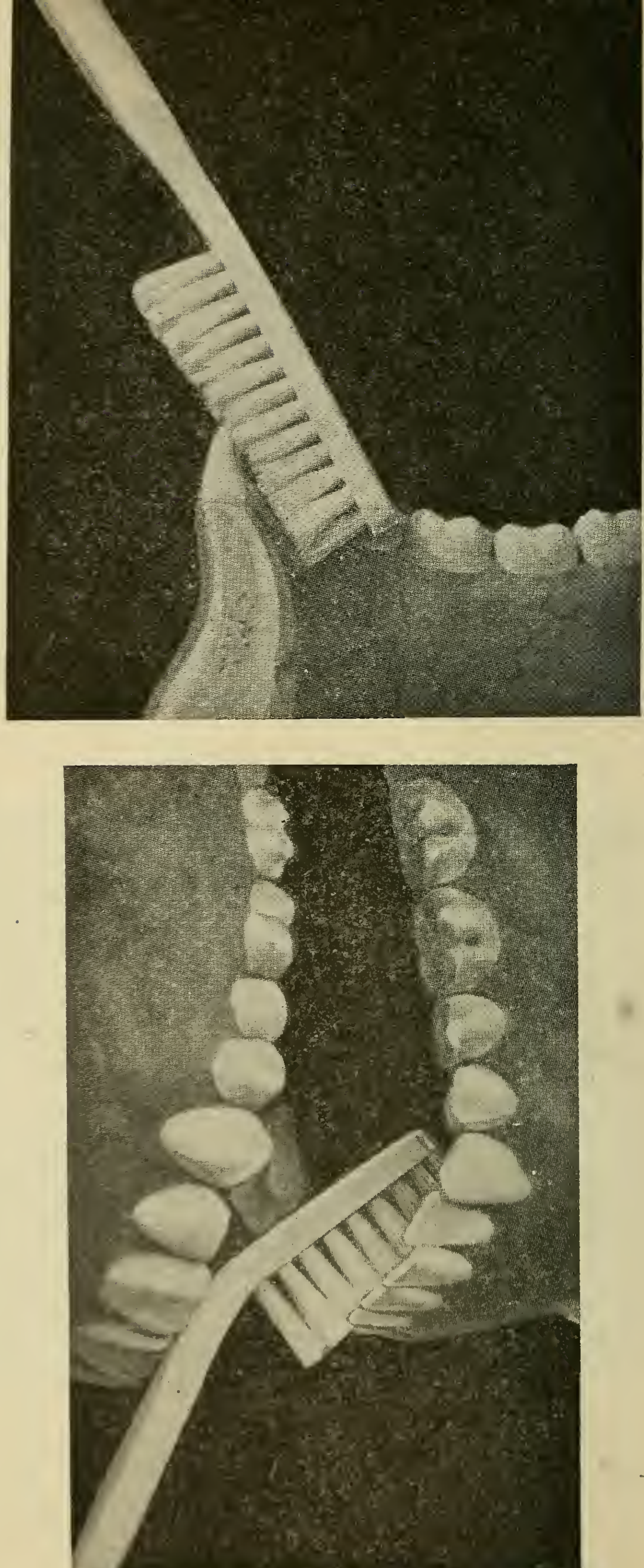


Figs. 51, 52, 53. Three tooth-brushes, actual sizes, for baby, youth and adult. All three have the bristles set sufficiently far apart and the brushes are generally good form. The brush in Fig. 51, ordinarily sold as a youth's size, is by far the best size for most adults, as there is better opportunity to manipulate it in the mouth. While some persons may use a brush as large as Fig. 53, it is too large to permit of proper movements in most mouths. (Black.)





Figs. 54 and 55. A "youth's" size brush to the buccal of the upper molars. In Fig. 55 the ramus in section is shown in its position in many mouths when the mouth is open, preventing the brush from reaching the third molar. In Fig. 54 the ramus is shown in its position when the mouth is closed, giving additional room for the brush. (Black.)



Figs. 56 and 57. In brushing to the lingual of the lower incisors the brush should be held parallel to the long axis of these teeth. Many people fail to brush the gums and gingival portions of the teeth in this position. If the brush has a handle bent as in Fig. 57 the end bristles will touch the gum.

fitted with a large rubber bulb capable of holding $1\frac{1}{2}$ ounces of water. This should be fitted upon a nozzle 3 inches long, ending in a squirting extremity bending around in a short curve, and possessing an opening $1\frac{1}{2}$ mm. in diameter.

With such a syringe it is possible to cleanse the subgingival spaces, both the proximal, besides the labial, buccal, and lingual. It is also possible to remove the food débris from the interproximal spaces and to empty any pockets which may have resulted from the detachment of the peridental membrane. With a little experience one may pass over the whole of both dentures with 8 syringefuls of water, a single syringeful being used for one surface of one denture from its distal extremity upon the third molar to the mid-line between the incisor teeth.

The water will find its way to the deepest part of the subgingival space. In fact, the majority of patients will soon come to feel the lifting of the gingivæ as the water enters the subgingival spaces. The syringe is so effective in its cleansing powers that patients once learning its use gladly continue with it.

Almost everyone will fail in some particular in the routine of cleansing the teeth properly. For this reason the advice of a dentist is quite essential at regular intervals. It is quite necessary that the dentist should supervise the effectiveness of his patients' attempts in cleaning their teeth and point out to his patients in what details the cleaning may be insufficient.

Artificial dentures and bridges, removable and fixed, should receive even more attention than the natural teeth. The denture collects beneath it the exfoliated epithelium of the mouth. This becomes mixed in places with food débris. Both of these forms of débris decompose and the products of decomposition become not only offensive, but irritating to the normal mucous surfaces. Moreover, bridges and other artificial appliances, even more than the natural teeth, form crevices beneath their edges in which food particles and other matter may accumulate.

The artificial denture may be placed under running hot water. After it has been washed in this manner, it should be brushed with a special brush. For this purpose a small hand brush with rather thickly set bristles is best. (See Fig. 58.) Special care should be bestowed upon that portion of the plate which covers the alveolar ridge. After the plate has been cleansed, any remaining teeth

[illegible]

and the mucous surfaces upon which the plate fitted must be cleansed. It is of the utmost importance that such surfaces should be washed free of deposit.

The proper care of bridges goes back farther than the cleansing process after they have been placed within the mouth. It concerns the manner in which they have been fitted to the mouth. They must be made and fitted in a manner that renders their cleaning an easy matter.

"No part of a bridge should press on the mucous membrane It should be supported wholly by its abutments. Such an interval should exist between the edge of the bridge and the mucous mem-

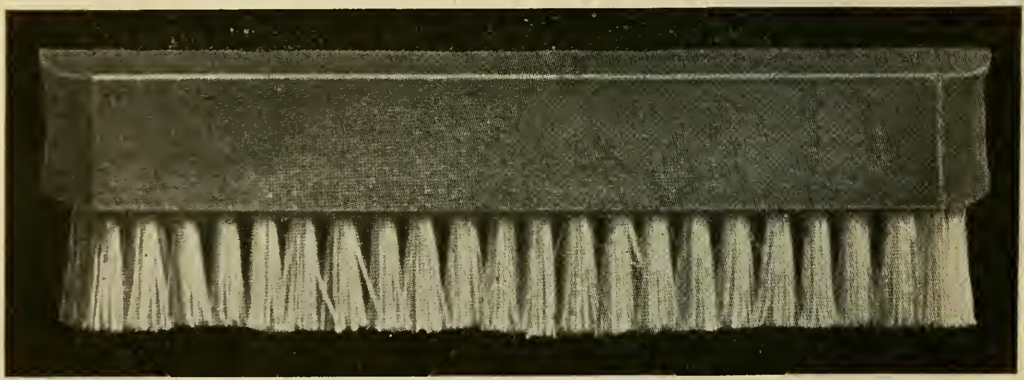


Fig. 58. Special hand brush for cleansing the artificial denture.

brane that a piece of tape can easily be inserted between the two and thus permit the rubbing of that part of the appliance which cannot be reached with the brush. For this to be effective the surface of the dummies towards the tissues should be convex from buccal to lingual rather than concave as many are made specially in the portion of the surface towards the lingual."

Too great insistence cannot be laid upon the painstaking care which is not only necessary to use in the construction of bridges, but also upon the frequent examination of them, and alteration of them from time to time, in order that they and the surrounding mucous surfaces may be efficiently cleaned. They are by far the most difficult intra-oral artificial appliance to keep clean. Even when as originally placed, they may be satisfactory, yet later they may become a serious menace to health and even to life.

The toothpick is better avoided than resorted to as a means of cleaning the teeth, certainly in the mouth of the normal individual, and with few exceptions in all individuals whose mouths have been put in proper condition. It accomplishes nothing that cannot more safely be accomplished by the brush and syringe. It is possible that the use of the toothpick is justified in certain individuals in whose mouths the interproximal spaces have been widened by a recession of the gingivæ, whenever such individuals after eating cannot have access to the toothbrush or syringe or cannot effectively clean their mouths by a simple rinsing process.

The danger which comes from the use of the toothpick is the harm which may result from the trauma which they are so liable to inflict upon the gingivæ. The constant irritation of the gingivæ by the pressure or actual wounding of the gingivæ is no negligible factor in the excitation of disease in the peridental membrane. When toothpicks are resorted to, care should be taken to select a good quality of toothpick, one hard and smooth enough to be free from the splinters so often found in the cheaper grades. Quill toothpicks are either too broad or too yielding to be of service without the infliction of undue trauma.

Rubber bands and wax silk floss are more efficient and less harmful than toothpicks for cleaning the interproximal spaces. When they are used, they should slowly be carried past the contact point, using in this manner great care not to injure the gingivæ. The time and effort consumed in cleansing each interproximal space in this manner are so considerable that they constitute rather serious objections to this method. Moreover, even with care it is not always possible to avoid injuring the gingivæ. For these reasons, in the absence of special peculiarities of the interproximal spaces, it is desirable to dispense with the use of rubber bands and silk floss.

The above considerations comprise those procedures which are most desirable for keeping the normal teeth and gingivæ healthy. When deviations from the normal conditions occur, such as the beginning of decays or abnormal interproximal spaces, it is essential that these deviations should be corrected by the dentist in order that they may not be the cause of continued decay or progressive inflammation of the gingivæ.

Beginning decays have been classified by Black into the following:

1. **Pit and Fissure Decays in the Enamel**—The pit and fissure decays in the enamel may occur in the occlusal surfaces of the bicuspids and molars and in the buccal surfaces of the molars and lingual surfaces of lateral incisors. The majority of these decays occur early, soon after the teeth erupt. They are important because bacteria may grow in them and increase the size of the decay by their products. While the position of these decays makes it possible for them to be cleansed by special care, it is far more practical to make these defects "self-cleaning" by a proper filling.

2. **Proximal Decays**—Proximal decays occur on the smooth surface of the enamel just to the gingival side of the point of contact. The majority of these decays occur between the 10th and 25th year. They can occur only after there has been a slight recession of the septal gingivæ. These decays may be prevented from extending, if only beginning by polishing the area to the level of the surrounding surface and thereafter conscientiously cleaning the interproximal spaces with tape or silk floss. An inch or two of the latter may be moistened and then dipped into pumice and used daily by the patient to clean an interproximal space so affected.

3. **Decays upon the Gingival Third of the Buccal, Labial and Occasionally upon the Lingual Surfaces**—The decays upon the gingival third of the buccal, labial and upon the lingual surface are less frequent and met with later in life, most of them after the 20th year. They can all be prevented by brushing the teeth. When of slight depth they may be ground down to the level of the surrounding surface and afterwards the surface kept clean by more careful daily cleansing of the teeth.

Of equal importance with the prophylaxis against dental caries is the prophylaxis against disease of the peridental membrane. Slowly and surely, unless protected from the various agencies which wear this only support of the teeth away, it gradually recedes from the roots of the teeth, not only leaving their roots exposed until the teeth actually fall out, but in the process forming between it and the teeth, will form chronic suppurating pockets which possess full potential powers for undermining the constitution of the victim.

The causes of inflammation of the peridental membrane are as follows:

1. **The Collection of Salivary Calculus upon the Teeth**—According to the researches of Black, salivary calculus is a deposit of calcoglobulin which when present in excess in the saliva becomes deposited upon the teeth at first in the form of a greasy, sticky, soft coating. It is insoluble in water and coagulable by heat from its solutions in neutral salts. When first deposited, it is easily removed by a stream of water as from the oral syringe. It soon, however, undergoes a hardening and becomes more and more difficult to remove. It can be readily removed within five to twelve hours after it is deposited, but after 24 hours the hardening has progressed so far that it is difficult to remove with a brush. After a week it can no longer be brushed away, and after one or two months instruments must be used to break it away.

To a certain extent the presence of this calcoglobulin in the saliva in a sufficient concentration to precipitate, depends upon the individual. The teeth of some individuals never collect calcoglobulin; in other individuals the greatest care is needed to prevent the formation of thick deposits, but the relation between generous diet and the tendency to the deposit of salivary calculus is so marked that even individuals most susceptible in this particular can wholly prevent the formation of calcoglobulin by eliminating from their diet that excess over and above an amount which is sufficient to satisfy their energy requirements. In other words, indulgence in an excessive diet causes excessive quantities of calcoglobulin in the saliva.

Salivary calculus is always deposited upon the teeth (never upon the mucous membranes), at the free margin of the gingivæ. If allowed to remain it thickens and by pressure it destroys the gingivæ, which become thickened and shortened. (See Figs. 59, 60, 61, and 62 for illustration of the progressive shortening of the gingivæ, even to the destruction of the alveolar borders. See Figs. 63, 64, 65 and 66 for further illustration of the destruction of tissues due to salivary calculus.) The prophylaxis of the condition depends upon an avoidance of an excessive diet and of the faithful use of the toothbrush and oral syringe.

2. **Serumal Calculus**—The term serumal calculus is applied to a deposit of calcoglobulin upon the enamel of the subgingival

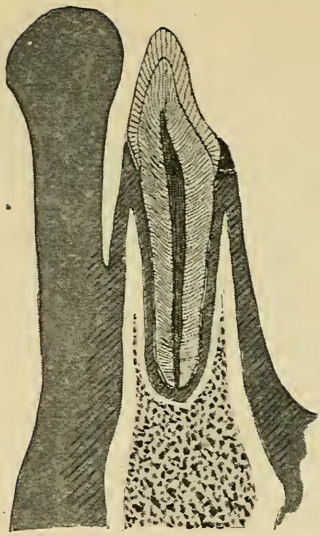


Fig. 59. Drawings to illustrate the progressive destruction of the investing tissues caused by deposits of salivary calculus.

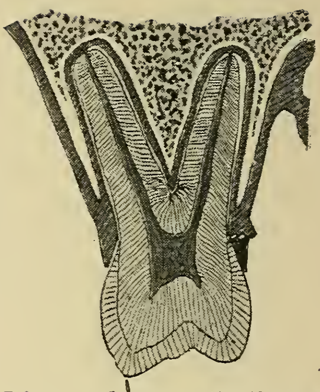


Fig. 60 shows a similar deposit on the buccal surface of an upper molar.

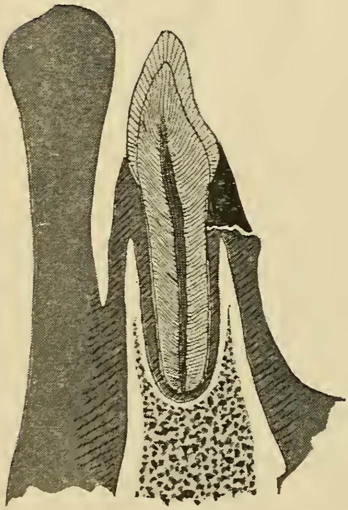


Fig. 61 shows a slight deposit on the lingual surface of a lower incisor which has caused a gingivitis only, not having progressed far enough to involve the attachment of the peridental membrane to the cementum.

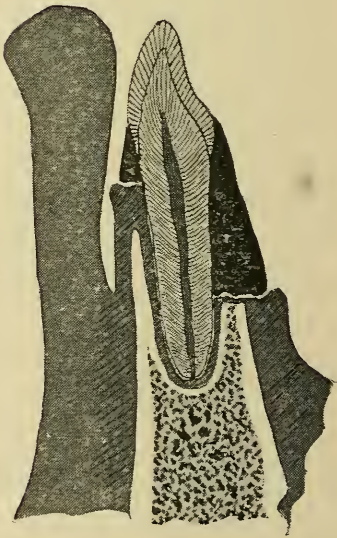


Fig. 62 shows a more extensive accumulation on the lingual of a lower incisor than shown in **Fig. 61. It** will be noticed that the gingival line of the tooth has been passed and the deposit has almost reached the crest of the bone.

Fig. 63. Illustrations showing the destruction of the investing tissues by deposits of salivary calculus.

Fig. 64 is a reproduction of radiograph showing extensive destruction of the alveolar process.

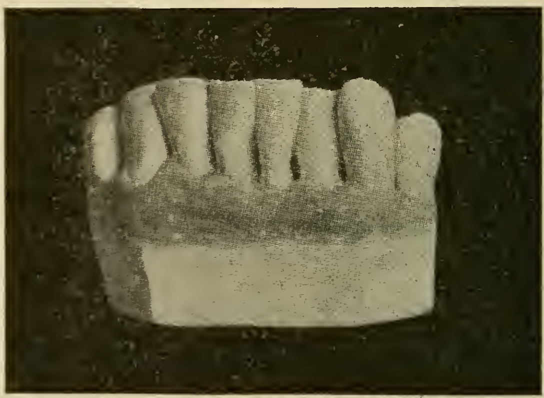


Fig. 65 is from a plaster cast of a case in which the deposit was nearly as extensive on the labial as on the lingual of the lower incisors. In this case the septal tissues were destroyed by the use of a wooden toothpick, rather than by the deposits.

Fig. 66 is from a skull. This shows the destruction of the bone, which is especially deep between the central incisors. Spec. from Northwestern University Dental Museum. (Black.)

space. The deposit in this instance does not come from the saliva, but from the excess of calcoglobulin contained in the serum bathing these spaces. This different origin is made evident by the contrast in the location of salivary calculus and the favorite sites of collection of serumal calculus. The former occurs more frequently upon the back teeth or those in relation to the salivary ducts, while the serumal calculus is more apt to occur in the front part of the mouth, especially upon the incisors and bicuspids.

While it should generally be expected that salivary calculus should be present in mouths in which serumal calculus is present, such is not necessarily the case. This circumstance is probably due to the fact that local conditions of the nature of a beginning irritation of the gingivæ, or differences in which certain portions of the denture are subject to natural processes of cleansing during mastication, have something to do with the deposit of one or the other form of calculus. Serumal calculus is more compact and harder than salivary calculus. Its color is dark brown, often intensely black, and when broken, washed and dried it becomes lustrous. (See Figs. 67, 68 and 69 for deposits of serumal calculus and the manner in which they may provoke a gingivitis.)

The prophylaxis of serumal calculus is the same as the prophylaxis of the salivary calculus: namely, the faithful use of the toothbrush and the syringe. The possibility of the formation of these deposits should necessitate regular visits to the dentist, who should, in those individuals who cannot be educated to keep their mouths free of the deposits, remove them at frequent intervals and at the same time instruct the patient in better methods of cleaning the teeth.

3. **Faulty Contact Points**—Unquestionably the most frequent cause of gingivitis is faulty contact points, particularly in the molar and bicuspid region, where the heavy work of mastication is done. An open space between two adjacent contact points means that particles of food, especially food of a stringy nature, will be crowded down upon the septal gingivæ with each occlusion in the act of chewing. As a result of repeated pressure and irritation, the tissue becomes inflamed and finally suppuration supervenes in the line of attachment of the peridental membrane to the cementum, extending in a direction from the occlusal surface

Fig. 67. Drawings to illustrate the positions in which deposits of serumal calculus occur on the surface of the enamel in the subgingival space. Deposits in this position are usually flat scales, while those on the roots are more generally nodular. Fig. 67 shows small deposit on labial surface of a lower incisor.

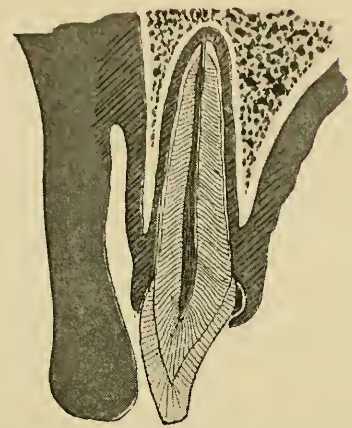


Fig. 68 shows a deposit of serumal calculus under the free gingiva on the lingual surface of the enamel of a lower incisor tooth.

Fig. 69 shows a similar deposit on the lingual surface of an upper incisor. Suppuration of the peridental membrane, resulting from deposits in this position, causes the teeth to move labially, and such cases are generally hopeless after much progress has been made.

of the teeth toward the apex. The inflammation may or may not be accompanied with the deposit of serumal calculus.

Lack of contacts between the teeth may be due to separations between teeth caused by the extraction of a tooth: if, for instance, a first molar is extracted, the second molar and second bicuspid will be drawn together, causing slight opening of the contacts on the opposite sides of these teeth. Uneven occlusal wear or occlusions originally abnormal upon the cusps may cause a separation or weakening of contacts. Weak contacts may be due to a weakening of the pull of the septal fibers of the peridental membrane. In such cases the pressure of certain kinds of food may be sufficient to force the contact points apart.

Decays beginning in the proximal surfaces of the teeth may progress until the occlusal surface of the enamel is undermined and finally the undermined margin lost. Through such a defect the food during the mastication will be forced down upon the septal tissue. Fillings and crowns may be so improperly finished that they fail to restore the proper contact with adjacent teeth. Too broad a contact between teeth may be responsible for entrapping stringy food between the teeth and for resulting in undue pressure upon the septal gingivæ. Sometimes such broad contacts may depend upon an abnormal position of a tooth which causes it to slant and thus come into contact with its neighbor by a wider surface.

Interproximal wear resulting from slight buccolingual motion of a tooth during mastication may lead to a widened and loose contact. In this manner facets of considerable size may be worn between adjacent teeth between the contact point. Gingivitis may be caused by the direct injury inflicted upon the gingivæ by the sharp irregular edges of proximal carious cavities, or by imperfectly finished filling, or by crowns or bridges which may have been improperly finished or which either impinge upon the gingivæ or allow abnormally large gaps between the gingivæ and teeth and which are so shaped that the particles of food may pack into the crevice. Finally, gingivitis may be due to direct injury of the gingivæ by either the dentist or the victim himself. One of the worst forms of injury may be due to the drawing of the ligature roughly down between the teeth upon the septal gingivæ or even the careless leaving of ligatures in place.

The gingivæ are not infrequently injured by carelessness in the use of instruments in the various operative procedures upon the teeth. The greatest care should be exercised in the restoration of the normal contact between teeth and in the protection of the gingivæ against the lodgment of food in abnormal crevices and pockets about the teeth; and finally against direct injury from improperly finished artificial work or the still more direct instrumental injury.

Two other subjects must be considered a part of the general discussion on the hygiene of the mouth. Both more properly belong to the field of oral surgery but their prophylaxis is so essentially of hygienic importance that their consideration here cannot be omitted.

They are the relation of chronic irritation within the mouth to the development of cancer in this cavity and the relation of hypertrophied tonsils and adenoids to ill health.

The Relation of Chronic Inflammation in the Mouth to the Development of Cancer—However much debated the cause of cancer may be, yet it is an established clinical fact that no exciting cause so frequently leads to the development of cancer inside the mouth as prolonged trauma to its mucous membrane. Such prolonged trauma may be caused by a sharp, ragged edge of a tooth or a rough, unprotected edge of a bridge or poorly fitting plate, a large solitary calculus or the presence within the mouth of chronic inflammation surrounding a carious tooth or the opening of a sinus leading down to an area of necrosed bone. All these conditions frequently lead to chronic ulceration which only too frequently leads to the development of true cancer. Another form of irritation not to be overlooked is the chronic irritation of tobacco smoke, particularly if there is added the additional irritation of a rough end of a pipe or the intensification of the effect of tobacco smoke upon some one place in the mouth as would result from the constant holding of the cigar or pipe in the same place in the mouth.

Finally it must not be forgotten that the association of tertiary syphilis and cancer is not uncommon. The superficial leucoplakias and the chronic diffuse productive inflammations occuring so often on the tongue in tertiary syphilis are not infrequent precursors of cancer.

The Relation of Adenoids and Hypertrophied Tonsils to Ill

Health—Excessive hypertrophy of the tonsils and adenoid tissue of the nasopharynx leads to ill health of quite a different character. These conditions usually occur in childhood but the evil train of consequences following them frequently persist through life. When this tissue becomes hypertrophied, it so fills the space of the nasopharynx that it interferes seriously with nasal breathing and renders deglutition more or less difficult. The nasopharynx is not infrequently completely blocked and during each inspiration and also during deglutition there occurs a rarefaction of the air in the nasopharynx which leads to increased congestion and secretion in the nasopharynx. The mouth is constantly held open and the pressures, including both the muscular pressure and atmospheric pressure upon the hard palate, are not counterbalanced as under normal conditions by the passage of air through the nose and the action of the lingual muscles, producing suction and a laterally spreading effect upon the hard palate. All of these factors are concerned during nasal respiration.

As a result of this altered muscular activity and changed air pressures within the mouth and nasal cavity the nasal space fails to develop to its normal size and capacity. It becomes contracted not only at its anterior and posterior openings and from the sides but also, and to a prominent degree, from below. The arch of the hard palate is very high. This alteration of the arch of the hard palate affects in turn the development of the teeth. The anterior teeth of the upper jaw become cramped together and tend to project forwards. The transverse diameter of the mouth is contracted. There is a tendency for the molars to depart from the vertical plane and be directed inwards. The deformity of the upper jaw seriously affects the development of the lower jaw as the teeth acquire those positions into which they are forced by articulation with their antagonists. Patients who have suffered with adenoids present a typical appearance. The nose is small, the anterior upper incisors project in front of the lower incisors. The mouth appears contracted in its transverse diameter and the arch of the hard palate is abnormally high.

The lower jaw is undeveloped and receding. The patients habitually breathe through the mouth and during the period of greatest hypertrophy which occurs during childhood and adolescence there is a constant discharge of mucus from the nose. The poor victims

appear to be suffering from a chronic cold with many acute exacerbations.

The effect on the general health and the development of both mind and body is most serious.

The afflicted individuals are constantly swallowing and aspirating the bacteria containing discharges from the nasopharynx.

The surface of the enlarged tonsils are covered with crypts and within these and the crevices between the adenoid papillæ the bacteria collect and develop and may enter the system either directly or by passing into the lymph and blood stream or they may be inhaled.

Tuberculosis in its various forms is a frequent complication of adenoids and enlarged tonsils. The most serious effect upon the victim, however, comes from the embarrassment of respiration and of the free access of oxygen to the lungs. It is as though the individual was constantly living in a confined atmosphere.

All these individuals are poorly developed as to their bodily size and muscular strength and this depression of the developmental activity includes the brain. All these victims show more or less blunting of their intelligence.

The contrast which these patients present before and after the operative removal of their tonsils and adenoids well emphasizes the serious stunting of their bodily and mental vitality.

Before operation many of these children appear half idiotic with their mouth constantly open and their bodies undersized and brains incapable of any serious mental effort.

They are behind their companions in all these particulars. Their backwardness at school is especially noticeable. After operation they actually begin to grow. Not only do their faces change but they rapidly overtake their companions physically and mentally.

QUESTIONS AND ANSWERS

Page 4

Q. Into what divisions may hygiene be divided, and describe the province of each?

A. See text.

Page 8

Q. What quantities of the three foodstuffs constitute a favorable diet, and what is the caloric value of each?

A. See text.

Q. What are the meats and what in general is the proportion of the three foodstuffs in the meats and their caloric value?

A. See text.

Page 10

Q. What is the relative digestibility of the meats?

A. See text.

Page 12

Q. What are the parasites of meat and fish, and how are they transmitted?

A. See text.

Page 18

Q. What are the dangerous bacterial diseases of meat, and what precautions must be taken to insure protection against them?

A. 1. Tuberculosis.
2. Typhoid. Fever & cholera
3. Ptomain poisoning.

See text.

Page 24

Q. What is the caloric value of eggs and the proportion of foodstuffs in them?

A. See text.

Q. What is the proportion of the foodstuffs in milk an' its caloric value per 100 c. c. of cows' milk?

A. 71.2 calories.

Page 26

Q. What are the factors contributing toward the bacterial contamination of milk, and how may they be avoided?

A. The introduction of pathogenic bacteria from the cow, including especially pyogenic organisms and tuberculosis, of certain pathogenic bacteria after milking, especially typhoid. The unnecessary increase of the unavoidable inoculation which has occurred during milking and distribution, and unnecessary increase of the contamination after milking. See text for precautions.

Page 32

Q. What are the vegetable foodstuffs?
A. See text.

Q. What are the cereals, and what is the nutritive value of the cereals?
A. See text. 256.1 to 352.8 calories to 100 grams.

Page 36

Q. What are the legumes, and what is the nutritive value of the legumes?
A. See text. 287.8 to 346 calories.

Page 38

Q. What are the farinaceous preparations, and what is the nutritive value of farinaceous preparations?
A. See text.

Page 40

Q. What are the roots, and what is the nutritive value of the roots?
A. See text.

Q. What are the vegetable fruits, and what is their nutritive value?
A. See text.

Q. What is the nutritive value of the mushrooms?
A. See text.

Page 44

Q. What is the relative nutritive value and systemic effect of tea, coffee and cocoa?

A. With the exception of cocoa, the caloric value of which is 5.68 per gram, the nutritive value is negligible. The stimulating value upon the nervous system, the heart and kidneys is considerable, and about equal in degree for tea and coffee, although varying much according to the strength of the infusions made. With many individuals the effect is very harmful. In the case of cocoa the stimulating effect is much less.

Page 46

Q. What are the different methods of preserving foods, and their relative value?
A. See text.

Page 48

Q. Of what hygienic importance is the contamination of preserved foods by metals?

A. Preserved food may be contaminated by lead, copper, zinc, nickel and tin. None of these, with the exception of lead under extreme circumstances, is harmful. An appreciable quantity of lead may be dissolved by acid containing preserved foodstuffs from the metallic cap used to cover certain preserved foods.

Page 52

Q. What is the composition of air?
A. See text.

Theine = Caffeine –

Coffee = 1–3 %. Tea – 3–4 %

Page 54

Q. What is the hygienic effect of a close atmosphere, and to what is it due?

A. It causes a train of very uncomfortable symptoms, characterized by headaches, nausea, increased heart action and general depression. These are due entirely to the increased percentage of moisture, heat and psychic influences, and not to increase of any toxic elements or of carbon dioxid.

Page 56

Q. What is the relation of the bacterial contamination of air to health and the degree and character and source of such contamination?

A. The air never contains sufficient bacteria to make it a source of danger from the mere number of the bacteria, but is dangerous solely because of the presence of pathogenic bacteria which it may contain, and of course the greater the number of these the more dangerous it becomes. The more important air transmitted organisms are tuberculosis, diphtheria, streptococci and the various exanthemata. These are more seriously contaminators of the air in the vicinity of patients ill with these diseases, as in houses, hospitals, and especially the rooms in which such patients live.

Page 58

Q. What is the relation of sewer gas to health?

A. See text.

Page 64

Q. What is the relation of contamination of the air by smoke and dust to health?

A. See text.

Page 70

Q. What chemical changes go on in the soil?

A. See text.

Page 74

Q. What is meant by ground water, and what is its relation to health?

A. Ground water is the water saturating the soil at varying depths below the surface. Its height is directly proportional to a certain part of the ill health of the community.

Page 76

Q. What are the sources of soil pollution?

A. Animal bodies and animal excretions.

Page 78

Q. What are the purifying agencies in the soil?

A. Most important, the saprophytic bacteria of the soil, and secondly the deodorant and purely chemical purifying reactions of the soil itself.

Page 84

Q. What are the soil diseases in the sense that the soil not infrequently transmits them?

A. Chiefly tetanus and malignant edema, and possibly anthrax, apart from those diseases depending for their transmission upon the water in the soil or the water of the natural water courses and basins. These are malaria and uncinariasis, typhoid and cholera.

Page 88

Q. Classify waters.

A. See text.

Page 92

Q. What substances present in natural waters indicate their pollution and why?

A. See text.

Page 94

Q. What is hardness? To what is hardness due? What is the relation of hardness to health, and what other importance does it possess?

A. See text.

Page 96

Q. What function is performed by the saprophytic bacteria in water?

A. Destruction of the organic nitrogenous compounds by the process of nitrification. Partly as a result of this action and some not clearly understood direct antagonistic action to pathogenic bacteria, or limitation of the vitality of the latter.

Q. What is the vitality of pathogenic bacteria which are more frequently transmitted by water?

A. Cholera, 7 to 20 days. Typhoid, indefinitely, according to the condition of the water, its degree of pollution and exposure to the sunlight.

Page 100

Q. Describe the different kinds of wells and conditions leading to their pollution.

A. See text.

Page 106

Q. What are the natural agents contributing to the purification of water?

A. See text.

Page 108

Q. What are some of the artificial methods of purifying water, and their relative advantages?

A. Filteration, public and domestic. Boiling. Chemical. Filteration with boiling is the best. Boiling of natural waters, the contamination of which is possible, is necessary. Filteration of public water supplies is most desirable. Chemical methods are to be avoided.

Page 112

Q. Describe a public filter and the conditions insuring its proper operation.
A. See text.

Page 122

Q. What are the water-borne diseases? How is pollution accomplished, and how may it be prevented, or at least infection avoided?
A. Typhoid, cholera, dysentery, round worms, pin worms, uncinariasis, filaria.

From the discharges of sick individuals.

By properly burying the disinfected discharges of sick individuals in the case of isolated cases in country districts.

By disinfecting the discharges of city cases and subjecting city sewage to thorough nitrification and filteration.

By public filteration of public water supplies.

By private boiling of all suspicious drinking water from public water supplies.

Page 140

Q. Mention some of the more important hygienic considerations in house construction.
A. See text.

Page 142

Q. What are some of the special hygienic considerations pertaining to school buildings?
A. See text.

Page 142

Q. What is the ideal quantity of fresh air required by each individual?
A. See text.

Page 144

Q. What are the natural forces of ventilation?
A. See text.

Q. What is the most desirable arrangement of inlets and outlets for ventilation purposes, and other special artificial arrangements for ventilation?
A. See text.

Page 154

Q. What is the minimum space which should be allotted to each individual in dwellings or public halls, and the conditions upon which such a calculation is based?
A. See text.

Q. Define the three methods of heat transmission; give an illustration of each and its advantages and disadvantages.
A. See text.

Page 156

Q. How may the open stove be made to furnish heat by conduction and convection, and at the same time utilizing the external fresh air? Explain in detail.
A. See text and Fig. 27.

Page 158

Q. Explain a method of heating by complete combustion and its advantages.
A. See text and Fig. 28.

Page 160

Q. Explain the different methods of transmitting heat from a central plant in a house and the relative advantages and disadvantages.
A. See text.

Page 164

Q. What are the different methods of artificial lighting and their relative advantages and disadvantages and dangers?
A. See text.

Page 168

Q. To what extent is plumbing of hygienic importance?
A. Though bacteria may be transmitted through a house from defective sewage, yet the danger of infection from this source is practically nil. Defective plumbing is chiefly to be avoided because of the indirect psychic effects, and because it attracts insects.

Page 176

Q. What two kinds of sewage are there?
A. See text.

Page 186

Q. Of what economic value is municipal sewage?
A. See text.

Page 188

Q. What are the present day methods of disposal of municipal sewage? Discuss their relative value.
A. 1. Sewage irrigating system. Of little economic value in cold climates. Of considerable value in warm climates, with sandy soils. It is efficient and harmless.
2. By the discharge into water courses. Is cheap and probably safe when the river water is not used for long distances below the town or city, but in general to be condemned.
3. By contact filteration or trickling filteration. Fairly efficient, and to be recommended under certain conditions.
4. Best by chemical precipitation; sedimentation and complete nitrification in special tanks and filteration of the effluent.

Page 204

Q. Explain the relation of the peridental membrane to the preservation of the normal condition of the teeth.
A. The cementum derives its nutrition from the odontoblasts of the peridental membranes. Any inflammatory process within this membrane causes it to separate from the cementum. A partial separation leads to a greater separation and to the formation of pus pockets between it and the cementum. The porosity of the cementum contributes to the chronicity of the process. Once started, quite aside from the continuation of the primary cause, a vicious circle is started which ends in total destruction of the peridental membrane, alveolar border and loss of the teeth.

[illegible]
upon the [illegible] for the [illegible]
when the [illegible] are detached [illegible] responsibility [illegible]
→ [illegible]
[illegible]

Page 208

Q. What are the four pathological processes leading to destruction of the teeth?

A. 1. Dental caries.
2. Chronic suppurative gingivitis.
3. Pulpitis.
4. Acute alveolar abscess, with or without ensuing alveolar osteomyelitis.

Page 210

Q. What are the causes of dental caries?

A. The invasion of the tooth or its destruction from the surface by acid-forming bacteria growing in improperly drained retention places, in which the bacteria and particles of food find lodgment. These may be:
1. Pit and fissure decays in the enamel on occlusal surfaces of molars and bicuspids and lingual surfaces of incisors.
2. Proximal decays or decays in the enamel just to the gingival of the contact point.
3. Decays upon the gingival third of the buccal, labial and lingual surfaces.
4. Chronic suppurative gingivitis or any of its causes.

Q. What are the causes of chronic suppurative gingivitis?

A. 1. Any of the causes of dental caries.
Those more especially related to chronic suppurative gingivitis are:
2. Collection of serumal or salivary calculus.
3. Faulty contact points, and its various causes. See text.

Page 212

Q. What are the causes and possible course of acute pulpitis?

A. Direct infection of the pulp from opening the chamber by dental caries, or by dental operation, or by hemotogenous transmission, or thermal or mechanical trauma. Its course may be:
1. Resolution.
2. Apical abscess, which may lie dormant or cause progressive osteomyelitis of ranging degrees of severity or even systemic infection.

Q. Outline the prophylaxis of the preceding pathological processes.

A. See text.

Page 244

Q. What is the relation of chronic inflammatory or mechanical trauma to the development of cancer?

A. See text.

Page 246

Q. What is the relation of hypertrified adenoids and tonsils to deformity of the mouth and general health of the patient?

A. See text.
